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POWER STUDIES IN ILLINOIS COAL MINING

BY

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(THIS REPORT WAS PREPARED UNDER A COÖPERATIVE AGREEMENT BETWEEN THE ENGINEERING EXPERIMENT STATION OF THE UNIVERSITY OF ILLINOIS, THE ILLINOIS STATE GEOLOGICAL SURVEY, AND THE U. S. BUREAU OF MINES)

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POWER STUDIES IN ILLINOIS COAL MINING

I. Introduction

1. *Objects of the Investigation.*—This bulletin has been written in response to requests received from numerous Illinois coal operators for dependable information concerning various phases of their general power problem. The possibility of lowering power costs is being carefully considered by all progressive operators, and more particularly by those who have not already introduced up-to-date improvements.

Evolution in mechanical processes has necessitated changes in the usage of power for coal-mining activities, as has been the case in other industries. Some of the improvements have lowered costs of coal production per ton by merely increasing production rates, while other mechanical innovations have lessened costs by minimizing manual labor. Contemporaneously with this mechanical advancement there has been an increasing adoption of electrical power. Such power, at first generated locally, is now obtainable from utility companies, and operators desire data that will enable them to decide as to the advisability of contracting for such service.

Another inquiry pertains to the relative requirements for power by the several branches of coal mining. Many mines in the state are operated partly by steam power and partly by electric power; and usually the electric power comprises both direct current and alternating current. Mixed-power conditions always offer difficulties in allocating satisfactorily the operating costs at coal mines. Since many operators under such conditions have been unable to calculate their actual power expenses, the effort is made to assist them in deriving such heretofore deficient but important information.

These are among the various practical phases of the coal mine power-cost problem discussed herein. It is hoped that the suggestions resulting from this investigation will prove valuable to coal operators generally, although all data represent conditions and practices in Illinois only.

2. *Procedure of the Research.*—The problem was undertaken in the spring of 1922 by Professor Hoskin under the direction of the late Professor H. H. Stoek, then head of the Mining Engineering Department of the University of Illinois. A number of representative Illinois coal mines—mines of all sizes in the several fields—were selected for investi-

gation and data sheets prepared for tabulating the information obtained. Visits were made to most of these mines or to the offices of their operators. It was frequently found that the most useful statistics relating to power matters were obtainable not at the mines themselves, but at administrative or engineering headquarters. Eventually, as explained in Chapter IV, the research narrowed down to the consideration of but fifty mines.

Operators and engineers were generally most obliging in permitting inspections of their plants and records, with the result that a large amount of valuable information was gathered. All the collected data have been retained in confidence, although in many cases operators sanctioned a full publicity of their activities.

Most of the data were collected during the historic labor strike that held the Illinois coal-mining industry at a standstill for several months in the summer of 1922. This suspension of normal mining activities allowed operators, superintendents, engineers, and public-utility power officials ample time to check up their power performances systematically and to obtain detailed statistical information that could not have been procured during normal activities.

Several months were spent in collecting, classifying, and studying power statistics. The investigation was nearing completion when the sudden death of Professor Stoek and the appointment of the senior author as the acting head of the Mining Department necessitated interruption of the study.

The junior author assumed his duties on September 1, 1923, and shortly thereafter undertook the completion of this bulletin. It was found desirable to re-study thoroughly the original data and to incorporate much additional material that had accumulated during the interim.

3. *Acknowledgments.*—Thanks are extended to the officials of numerous Illinois coal-mining companies for their courtesies and favors, and also to the officers of several public-utility corporations for the valuable statistics, maps, and rate schedules furnished.

II. The Power Problem in Illinois Mines

4. *Early Use of Steam Power in Mining Work.*—In any large industry there are a few outstanding operating costs. Usually the leading items, in order of their magnitude, are the labor cost, the material cost,

and the power cost. In coal mining the labor cost is not only greater than any other single cost, but it actually exceeds the sum of all other costs and, therefore, in a large measure dominates the economics of the industry. However, it is aside from the purpose of the present investigation to enter into any discussion of mine-labor expense further than to remark that, because of legal restrictions and labor agreements, it is impossible to lessen it by direct reduction of wage scales. Hence any effort to reduce gross mining costs in this state must be directed along other lines.

The coal-mining industry has evolved from its primitive stages in which muscular effort, both of men and of animals, accomplished all results, to its present stage in which practically every operation is performed mechanically. Coincidentally, in this evolution, skill in the use of the pick has come to be unnecessary and the work of the coal miner, or loader as he is now more commonly called, consists largely of shoveling. Many of the expert duties formerly performed by the coal miner are now handled by other classes of mine employees or by machinery.

It was logical that the machines adopted early in coal mining work should be driven by steam generated through the combustion of coal. Operators considered fuel their cheapest item of consumption or supply, the coal used under boilers being regarded as worth little or nothing. For many years steam was the sole form of power used in driving hoisting, ventilating, pumping, and tipple machinery. As a rule these classes of machinery are relatively close to the boiler house. The use of steam was eventually extended, however, until it was not uncommon to see at coal mines surface pipe-lines, often poorly insulated, conveying steam hundreds and even thousands of feet to fans at distant shafts or to pumps at ponds or other sources of water supply. This practice would be considered indefensible in industrial plants of any other kind.

5. *Introduction of Compressed-Air Machinery.*—When a demand arose for mechanical means of performing underground mining operations that were remote from the power houses, it was necessary to utilize some form of power other than steam, and compressed air was adopted as a suitable form of transmissible power. Punchers were invented to cut the coal, and compressed-air locomotives were devised to fit mining conditions in haulage. These types of machines were popular for a time, although the losses of power due to pipe-line leakage and friction were always heavy. With continually increasing transmission distances these line losses eventually became prohibitive. In but one of the mines

selected for study is compressed air used for cutting coal; it is not used at all for driving locomotives; and at but one mine is it used for pumping—to operate two gathering pumps. Compressed air continues to be generated in small amounts at some mines, simply for driving such small types of apparatus as bit sharpeners and cement guns, for blowing dust from electrical equipment, and for operating small rock drills when taking up bottom, taking down rock, or driving through horsebacks or other geological deformations. In general, however, the generation of compressed air scarcely enters into coal-mining costs.

6. *Development of Electrical Coal-Mining Equipment.*—Electric power, which has come to be used almost universally in other industrial lines, has been gradually adapted to coal-mining practices. It has not only supplanted manual and animal labor, but it has taken over the duties formerly performed by compressed air, which is now almost obsolete in Illinois practice. We now find this form of energy performing every mechanical step in the production of coal. It handles pumping, haulage, coal-cutting, ventilation, illumination, screening, and loading. Illumination, both surface and underground, is universally electrical, but this item of cost is relatively insignificant.

In earlier years there were decided objections to the use of electricity, based chiefly upon the danger to men or animals of injury or death from coming in contact with electrical conductors, and the further danger, in gassy mines, of explosions caused by electric sparks. However, these hazards have proved to be less imminent than was anticipated. Electric machines are now built in such a way as to prevent ignition of mine gases and the chances of electrocution are minimized by various safety devices and precautions.

7. *Possibilities of Mining Cost Reduction.*—It is not within the scope of this bulletin to study the cost of animal power, though it accomplishes much work that would otherwise require some form of mechanical power. Similarly, although men continue to perform mine work that might be done mechanically, no account is taken herein of their wages, such cost items being customarily charged to labor rather than to power.

Coal-mining operators have succeeded in reducing mine-labor costs by the introduction of labor-saving coal-cutting machines. While the art of coal mining has been thus so changed as to reduce considerably the number of miners required, the saving in labor costs has entailed increased costs for power. It is possible that invention will make it possible to displace yet more mine workmen by mechanical devices (such as, for instance, power loaders) but it would seem that the limit of such displacement is nearly reached. With no substantial reduction in wages possible, with little prospect of any considerable relief from high costs of supplies, and with the certainty that there will be a somewhat increasing demand for power in the future, it would appear that any appreciable lessening of total mining costs must come through economies in the generation and utilization of power, and through increasing production rates by the application of power.

8. *Data Previously Available on Mine Power Costs.*—Although power costs stand next in magnitude to labor costs in Illinois coal mining, few coal-mining companies in Illinois have any definite knowledge regarding their own power requirements in terms of units of power, or of the power cost per ton of coal in the different branches of their mining operations. This lack of knowledge applies not only to the steam consumed, which is difficult to determine owing to the lack of simple means of measurement, but to electric power, which is readily metered. At some of the older mines no information whatever is obtainable regarding even total power costs. The owners themselves have but vague notions as to what portion of their gross expenses is assignable to power consumption. Such ignorance cannot prevail at mines operated exclusively by purchased electric power, for the power bills are monthly informers on this score.

Some companies pay no attention to the segregation of their power costs according to various uses. At mines using steam to drive the hoists, fans, and main pumps, no figures are available for the relative amounts and costs of steam consumed by each operation. The problem is particularly difficult at mines in which part of the machinery is driven by live steam and the rest by electricity generated locally from steam. The steam for these different purposes is generally drawn from the same batteries of boilers and no attempt is made to apportion the cost to the separate operations.

The heating of water for wash-house purposes is regarded as power consumption. According to common practice in Illinois the water is heated directly in the main boilers or by live or exhaust steam. Therefore, even at a so-called wholly electrified mine at least one boiler is maintained in operation. Eventually, perhaps, operators of such mines will use electric water-heaters. Ordinarily the cost of heating wash-house water is very small.

This review of the conditions prevailing in Illinois coal mining indicates that the present study is limited almost exclusively to steam and electricity as the forms of power that enter into costs. The problem, however, is not simple; due to the combinations of these two forms of power in driving the numerous kinds of mining machinery, it is very complicated. The study is complicated further by the use of both direct and alternating current.

Throughout this bulletin no account has been taken of the cost of erection of the power plants nor of any of the usual overheads such as depreciation, amortization, interest on investment, or taxes. Likewise the power cost given does not include such charges as management and office expense. In short, as herein discussed, the cost of power generation covers only the charges for coal, water, supplies, repairs, maintenance, and labor. In some cases of local generation of electric power by the use of steam, the wage of one additional man is included.

III. Uses of Steam and Electricity at Illinois Coal Mines

9. *Comparison of Mining with Other Industries.*—One would expect that, of all industrial plants operated by steam power locally generated through the combustion of coal, Illinois coal mines might show the lowest cost per unit of power. But this is not the case. Generally the boilers in use at coal mines are not as efficient as those at other industrial plants. At some mines feed-water is scarce or unsuitable so that the requisite boiler supply is unduly expensive. Generally, too, the steam-consuming units, such as fan engines, steam pumps, hoists, and generator engines are less efficient than corresponding units in other industrial plants.

While it may not be fair to compare power-generating costs at establishments so much unlike as a coal mine and a public-utility plant, it is interesting to note the fact that in many cases public-utility companies buy coal from mines at a considerable distance, pay freight on the coal from the mines to their power plants, burn it in generating electric power, and then are able to transmit and sell that power back to the mines not only at considerable advantage to the mine owners but also at a profit to themselves.

10. *Relative Advantages of Steam and Electricity.*—One question on which there are diverse opinions among the coal-mining operators of this state is that of the relative reliability and cost of steam and electricity in hoisting and in ventilating—especially in hoisting. The complete

electrification of several industries has been accomplished, and it is predicted that railroads will ultimately use electric power almost exclusively. One need not be regarded as unduly visionary if he imagines the eventual complete electrification of all coal mines. While this reasoning prevails among many coal operators and engineers, there are other officials who maintain that steam is not only more dependable than electricity for driving hoists, fans, and main pumps but that, with proper modern equipment, it can perform such duties at less expense than can electricity, be it either locally made or purchased.

There are strong arguments both for and against each form of power. Pertinent questions are: (1) Which form of power is preferable from a safety standpoint? (2) Steam being cheap and reliable, why complicate matters and increase equipment by using electricity? (3) Under what conditions is a mine owner warranted in generating all of his power, both as steam and electricity? (4) Under what conditions is he warranted in purchasing part of his power as electricity? (5) When is he warranted in purchasing all of his power as electricity?

Conditions vary so greatly at different mines that it has seemed impossible to answer such questions except for one mine at a time. If one considers such varying conditions as depth of coal seam, thickness of seam, quality of coal, area of workable ground, geological structure (rolls, faults, pinches, bands), amount of mine water, extent of present and future workings, available supplies of boiler and condensing water, costs and availability of purchased power, character and amount of present equipment, costs of alteration of plant, and average daily production and market for output, the force of this statement will be appreciated.

The data covering the relative advantages in the use of steam and electricity indicate that the case of each mine is indeed a problem in itself. At the same time, deductions from these data may prove helpful to many Illinois operators in enabling them to compare their costs with the costs of other operators having either similar or dissimilar mining conditions and types of installation.

Comparisons of this sort may suggest certain changes in equipment or practice that will lessen power costs. It might be found that a substantial betterment would follow radical changes in boiler-house equipment alone. Possibly costs per ton might be lowered if a fan were driven by electricity instead of by steam. In passing, it may be remarked that mine ventilation places a constant load upon an electrical circuit and therefore secures the most favorable rate for purchased power. Under certain conditions that may be adverse to the cheap generation of steam but favorable to the purchase of electrical power, an operator might be justified in putting his mine upon a wholly electrified basis.

During the past three or four years numerous newly opened mines have been wholly electrified. In some instances, even during shaft-sinking, electrical energy has been used for hoisting and, the claim is made, at considerably less cost than if steam had been employed. When this practice is followed, the permanent hoisting equipment, designed for the maximum capacity of the mine, is installed before shaft-sinking begins; but all other equipment need be only of such capacity as to carry the actual loads occurring at definite periods in the development and expansion of the mine. Electric motors are easily replaceable by larger units upon short notice and at nominal expense. There is an elasticity in the adaptation of electric power to changing demands that is not possible with steam-driven apparatus.

IV. Characteristics of Typical Mines Selected for Study

11. *Selection of the Group of Mines to be Studied.*—For this investigation it was deemed unnecessary to gather data from every one of the 1035 mines that normally are operated in the state. Not included in the study are 646 small mines that produce coal for local or wagon trade only, and about 16 open-pit or strip, slope, and drift mines, which are normally found among the shippers.

Of the remaining 373 mines whose production is regularly shipped by rail, 58 were chosen as typical and their power data were carefully collected. It afterwards developed, however, that at eight of these mines the data available were not adequate for all the purposes of the investigation. For this reason most of the conclusions presented herein refer to 50 mines only. The 50 mines at which adequate data were obtained represent all types of Illinois coal mines. They furnish examples of the use of various combinations of manual, animal, steam, compressed-air, and electrical power. There are included in this list mines using direct current, mines using alternating current, mines which use power generated at the mine, and mines which use power purchased from public-utility companies.

These differing conditions will obviously have a bearing on the power consumption and the distribution of power to the various branches of the operation. Many other factors influence power requirements at individual mines, thus producing the wide range of unit power consumption figures presented in this publication. The principal natural conditions affecting power requirements are: the thickness of the coal seam and of the overlying strata, which affect directly all activities from cutting to hoisting; the hardness of the coal, the extent to which hard impurities are present, and the nature of the immediate roof and floor, which affect mainly the mining and loading costs; and the extent of the workings and the amounts of water and of inflammable gases produced, which have to do mainly with pumping and ventilating power requirements. Other operating conditions which influence total power requirements are: the tonnage produced, the ratio of actual production to the capacity of the mechanical equipment, the steadiness of operation, the method of mining, and the physical condition of the mechanical equipment. These conditions vary widely in the mines studied.

The production per regular working day in these 50 mines varies from 650 tons to 5200 tons. The hoisting shafts vary in depth from 101 ft. to 650 ft. The distance that coal is hoisted from shaft collar to tipple averages 49 ft. The beds of coal in which these mines are operated vary in thickness from 3 ft. 6 in. to 10 ft. The smallest number of working days in 1921 was 100; the greatest number 306. General operating conditions at the individual mines are shown in Tables 4 and 8.

12. *Coal Cutting.*—The cutting or mining of the coal in the 50 mines is accomplished as follows: by hand, in 9 mines; by compressed-air machines, in 1 mine (24 machines); by alternating-current machines, in 4 mines (99 machines); by direct-current machines, in 36 mines (804 machines). Electric energy is therefore utilized for coal cutting in 80 per cent of these mines.

The average daily production of the nine mines having manual coal cutting is 1594 tons, as against an average of 3091 tons for mines using coal-cutting machines, or very nearly as 1 to 2. These nine mines produce 10 per cent of the gross tonnage. The one mine using compressed air produces 1200 tons per working day.

13. *Haulage.*—In two of the mines all haulage (both main and gathering) is performed by mules exclusively and in a few others it is by locomotives exclusively, but as a general rule both mules and locomotives are used for gathering. Main haulage by locomotives prevails in 48 of the 50 mines.

All locomotives in these 48 mines are electrically driven. For statistical purposes, locomotives are arranged in four general classes, viz:

trolley, reel-and-trolley, storage-battery, and combination. The straight trolley type is used exclusively in 17 mines and the storage-battery type exclusively in one mine. Thirty of the fifty selected mines perform their haulage with two or more types of locomotives.

The maximum number of locomotives in any one of these mines is 21. Straight trolley locomotives are used in 92 per cent of the mines, two or more types of locomotives in 60 per cent. Storage-battery locomotives, which appear to be increasing in number, are used in 36 per cent of the mines, and exclusively in one mine.

The total numbers of the different types of locomotives in use in the 50 mines are as follows: straight trolley, 176; reel-and-trolley, 154; storage-battery, 125; combination, 27; the total number of locomotives is, therefore, 482. The number of locomotives depending wholly or partly upon trolley wires is nearly three times the number of straight storage-battery locomotives which operate independently of wires, the exact ratio being 357 to 125.

14. *Shaft-Bottom Equipments.*—Car-hauls are used on the shaft bottoms of five of the mines, two of these having two car-hauls each. For operating these car-hauls steam is used in two mines and electricity in three. Car-lifts are operated by steam in four of the mines and by electricity in one. A car-dumper operated by compressed air is used in the one mine at which coal is hoisted in skips.

15. *Hoisting.*—Skip-hoisting is practised in but one of the mines, cages being used at all the others. For the cage-hoisting mines the average weight of coal per car is 2.9 tons, the minimum being 1.5 tons, and the maximum 5 tons. Hoisting is done at the average rate of 150 hoists per hour. The maximum number of hoists per hour is 240, and in this case the average amount of coal per hoist is 3 tons. The minimum number of hoists per hour is 57, and is at the skip-hoisting mine, in which 8 tons are handled per hoist. Steam drives 45 of the hoisting units and electricity, direct current, drives 5.

16. *Ventilation.*—At 38 of the mines steam is the only form of power normally used to drive the fans. One of these mines is equipped to use direct-current motors during emergencies. The fans at nine of the mines are normally driven by alternating-current motors. At one of these mines the fan may be driven also by a direct-current motor, while at two others steam engines are quickly available in emergencies. Direct-current motors exclusively are used to drive the fans at three of the mines.

17. *Pumping.*—Main pumping is done by steam at 25 of the mines. At 10 of these direct-current electrical units handle the gathering. At 25 of the mines all pumping is done by electricity. At 19 of these all gathering and main pumping is accomplished entirely through the use of direct current; at five, exclusively by alternating current. In one mine alternating-current motors drive the gathering pumps, while the main pumps are driven by direct-current motors.

18. *Box-Car Loading.*—Railroad cars may be mechanically loaded at seven mines but loaders are actually used at only three. Coal operators avoid box-car shipments whenever possible. Steam, alternating current, and direct current each operates one of the actively used car-loaders.

V. Power Characteristics of Selected Mines

19. *Classification of Power Costs.*—In this study of power it seems advisable to distribute power consumptions and costs to the fewest items that will fully cover coal-mining operations. Following this idea, coal mining is conceived as the art of excavating coal from its natural deposits and delivering it upon the earth's surface, this definition purposely omitting any washing or other dressing of the coal. There are five different power-absorbing processes involved in the procedure as thus restricted in scope, these being mining or undercutting, haulage, hoisting, pumping, and ventilation. These operations may be designated underground work as distinguished from numerous other activities that occur above ground, such as the screening, car-loading, and all shop practices. Illumination is also necessary underground during working shifts and above-ground at night. Usually, however, the amount of power consumed by electric lighting is insignificant in comparison with that consumed in other ways, and for simplicity in the present discussion it is combined with surface activities into one item of power consumption and cost, viz., Miscellaneous.

Under this arrangement, then, the power requirements in Illinois coal mining are discussed under six heads, five of which represent major operations. The analysis of many cases indicates that the average power requirement for these five major items combined is almost exactly 90 per cent of the total consumption. In the few cases where coal-washing plants are in operation at the mines, if washery costs were included, the sixth item, Miscellaneous, would rise from its normal 10 per cent to an average of 21.6 per cent. Washery mines, therefore, call for separate study, or washery costs must be omitted when comparing power costs at such mines with corresponding costs at the non-washing mines. The latter plan is followed herein.

20. *Classification of Mines with Regard to Form of Power Used.*— The 50 mines selected have been arranged into seven classes according to the utilization of steam and electric power in the five major operations. Briefly explained, the first class includes mines making a maximum use of live steam, the seventh class comprises mines making a maximum use of electricity, while intermediate classes cover the various gradations in the relative uses of these two forms of power.

Class A

In the two mines in this class steam is employed for every purpose to which it can be put in mining work, that is, for hoisting, ventilation, and main pumping. The mining of the coal is done by hand, and haulage is entirely by mules. Electricity is generally purchased in small amounts for illumination, but this expense is negligible. The average output of these mines is 1140 tons each per working day.

Class B

In the four mines representing this class steam is used for hoisting, ventilation, and main pumping, as in Class A, but electricity, direct current, is used for most, if not all, of the haulage. Mining is done by hand. These mines have an average output per working day of 1778 tons, the extremes being 1010 tons and 2600 tons, respectively.

Class C

In the mines in this class steam is used, as in the preceding classes, for hoisting, ventilation, and main pumping, but electricity is used in mining as well as in haulage, and in some instances for gathering pumping. This is the largest class of shipping mines in the state, and 19 were selected as typical. The individual daily production ranges from 650 tons to 4910 tons, the average being 3030 tons.

Class D

The mines in this class also are numerous, and 13 were selected as representative. In these mines steam is used for hoisting and ventilation, and electricity for mining, haulage, and all pumping. Provision is made at some of the mines for the use of electricity in driving the fans during emergencies. The average daily production of the 13 selected mines is 2920 tons, with a minimum of 1900 tons and a maximum of 4200 tons.

Class E

In the three mines in this class steam is used for hoisting only. Electricity is used for haulage, ventilation, and pumping. Mining is done by hand. The electric power for these three mines is purchased from public-utility companies. The average production is 1650 tons per working day.

Class F

In the four mines of this class steam is used for hoisting only. Electricity is used for mining, haulage, ventilation, and pumping. The average output is 3475 tons per working day.

Class G

Mines in this class are sometimes spoken of as "wholly electrified," this meaning that each of the five major operations is accomplished by electric power. The equipment at these mines is relatively modern. The mine operations consume amounts of electric power considerably above the capacity of the average mine power plant to produce, and hence they possess exceptionally large generating plants of their own, or purchase power from public-utility companies. The daily productions of the five selected mines in this class vary from 2635 tons to 4000 tons, the average working-day output being 3523 tons.

VI. Power Generation at Selected Mines

21. *Steam.*—Steam is generated at all Illinois coal mines, although, as in Class G mines, it may be consumed only to heat the buildings and the water for wash-houses. From such minimum proportions, steam generation varies in amount up to maximum conditions in central plants

Table 1
Classification of Mines According to Uses of Steam and Electricity in Major Operations
s—steam; e—electricity.

Operation	Class						
	A	B	C	D	E	F	G
Hoisting	s	s	s	s	s	s	e
Ventilating	s	s	s	s	e	e	e
Main Pumping	s	s	s	e	e	e	e
Haulage	mule	e	e	e	e	e	e
Mining	hand	hand	e	e	hand	e	e
Ratio of Steam to Electricity	3:0	3:1	3:2	2:3	1:3	1:4	0:5

that generate and supply electric power to two or more mines of common ownership. A central power plant of this sort often contains the best types of boilers, steam turbines, and generators, and is comparable to large, up-to-date power plants in other industries. Such a plant is usually located at one of the mines that it supplies with power.

At 39 of the selected mines the return-tubular type of boiler is used exclusively, at seven the boilers are of the water-tube type exclusively, and at four both types are used.

Altogether there are 283 boiler units at the 50 mines. The combined rated capacity of these boilers is 48 550 horsepower. The minimum capacity at any one mine is 50 boiler horsepower, the maximum is 3000 boiler horsepower. It should not be inferred that power is normally generated at these mines up to these capacity figures, for there are almost invariably idle boiler units held in reserve, while those that are used are not usually pushed to capacity.

At 43 mines equipped with return-tubular boilers the gross rated capacity of the 250 units is 36 375 horsepower, which means an average capacity of 145.5 horsepower per boiler. Similarly, at 11 mines equipped with water-tube boilers, there are 33 units with a total capacity of 12 175 boiler horsepower. Thus, there are about 8 times as many fire-tube boilers as there are water-tube boilers.

Mine-run coal is consumed under boilers at three mines; screenings, either crude or washed, are burned at the remaining mines. About one-sixth of the boilers are equipped with automatic stokers.

22. *Electricity.*—At mines not equipped to generate any electric power, current is purchased for illumination at least, if for no other use. At but one mine is electric power both generated and purchased for illumination.

All of the electric energy consumed at one mine in Class B is purchased, the mines of this class being those in which this form of power is required for haulage only (disregarding illumination). Three of the nineteen mines of Class C, in which electricity handles haulage and coal cutting, are supplied, in part or exclusively, with public-utility power. Each of the thirteen mines in Class D operates its mining, haulage, and pumping with electric energy generated either at the mine or at a neighboring common-ownership mine. The three mines in Class E operate regularly on purchased power for haulage, ventilation, and pumping. Mines of Class F operate their mining, haulage, ventilation, and pumping with privately generated electric power. Finally, of the five mines that are wholly electrified (Class G) four operate exclusively on public-utility power; the remaining mine has an exceptional plant of its own. These features are shown in Table 2, p. 32.

In local electric plants the ordinary prime mover is the steam engine, of many makes and types, from the antiquated to the very latest. Steam turbines are found in some of the newest plants only. Generators are driven exclusively by steam engines in 31 of the 50 typical mines and at these there are altogether 62 engines, each driving one dynamo. Eight of the generators are belt-driven, one rope-driven, and 53 direct-connected. The engines include fourteen makes. In capacity they vary from as low as 35 kw. to a maximum of 425 kw. The combined or gross capacity of the 31 plants is 11 590 kw. Generating units are installed at these 31 mines, but not all of them are ordinarily operated nor are many of them ever operated at full-load capacity. At 24 of the 31 mines there are two or more independent generating units. At a number of these mines the generating sets usually stand idle, being retained for service in emergencies only, and the power for mining operations is purchased or secured from neighboring common-ownership mines.

Two of the typical mines are operated exclusively with current generated at the mines by steam turbines. Three of these four turbines use high-pressure steam, the other runs upon a mixture of live steam from boilers and exhaust steam from the hoisting engine. Each turbine drives its own built-in, alternating-current generator.

The power plants at six of the mines contain both steam engines and turbines. Each of the nine engines is direct-connected to a direct-current generator and each of the eight turbines similarly drives an alternating-current generator. The capacities of these plants vary from 570 kw. to 2276 kw. The plant having this maximum capacity supplies power to other commonly-owned mines.

As in the matter of boiler capacities so here one must not infer that the foregoing capacity figures apply to normal electric generation about the coal mines. Reliable data as to actual steam and electric generation are meagre.

The foregoing discussion does not cover the new generating plant at Schoper, nine miles northeast of Carlinville, belonging to the Standard Oil Company. It is probable that this is the finest plant erected in the United States by a coal-mining company to generate power exclusively for its own group of mines. The generating capacity of this plant is 6250 kv-a.* The three alternating-current generators are direct-coupled to high-pressure turbines, two of which have a rating of 4000 horsepower each, the third having one-half this capacity. The current is generated at a voltage of 6600. The power has been provided primarily to operate the company's No. 2 mine which is about one-half mile distant. This mine is planned for an ultimate production of 8000 tons of coal per day, and its surface equipment is of this capacity, although the average working-day production at present is not over 3000 tons. Because of the fact that this mine plant is being operated far below its capacity the mine is not among those selected for power cost study.

VII. Power Consumption by Various Mining Activities

23. *Electrical Energy Consumed by Coal Cutting.*—In the production of coal from a going mine the undercutting or mining is the first operation to consume power. In the nine mines of Classes A, B, and E, this work is done entirely by hand. Their average daily production is 1593 tons. In one mine the coal is undercut with air punchers. Of the remaining 40 mines, in all of which mining is done by electrical cutters, there are but 29 mines for which reasonably accurate statistics are obtainable. The daily production of these 29 mines varies between 650 tons and 4910 tons. The average daily production is 2304 tons, somewhat less than the average for all the 40 mines that have electric mining—3099 tons—but this is not a significant factor in itself. The number of machines per mine varies from 5 to 41, the average being 22. The average number of tons mined per machine is 141, the lowest tonnage per machine being 69 and the highest 235. The daily consumption of energy per machine varies from a minimum of 40 kw-hr. to a maximum of 294 kw-hr., with an average of 77.54 kw-hr. The average amount of energy consumed in cutting one ton of coal is 0.55 kw-hr. but this varies in extreme cases from a minimum of 0.25 kw-hr. to as high as 2.26 kw-hr.

The minimum and maximum thicknesses of coal mined by electric chain machines in the group of mines examined were 4 ft. 9 in. and 10 ft. 0 in., respectively, which are approximately in the ratio of 1 to 2, whereas the extreme range of energy consumptions per ton of coal undercut—from 0.25 to 2.26 kw-hr.—shows a ratio of minimum to maximum of 1 to 9. In considering an operation carried out under such

For details, see "Standard Oil Mine Plant at Schoper," Power, Aug. 30, 1921, p. 312. Anon varying and in many cases unavoidably adverse conditions the comparison of power readings and performance records is likely to be misleading. Any attempt at generalization or averaging must be recognized as giving only approximately representative figures. In addition to height of coal undercut, there are various other factors which will affect the energy consumption in any given cutting operation. The most important of these conditions, all of which may vary considerably in different cases, are: the hardness of the coal, the presence or absence of hard impurities where the cut is made, the character of the bottom, the voltage available, whether direct or alternating current, the general condition of the machine, the condition of the cutter bits, the length of the cutter bar, and the skill of the machine operator and his helper. It is obvious, however, that with normal operating conditions the cost of undercutting per ton will depend upon the thickness of the seam, because the energy consumed is proportional to the area cut regardless of tonnage undercut. Where there are wide variations in thickness of coal being cut, therefore, it is most convenient to compute the energy consumption in watt-hours per square foot of area cut. In an anonymous article reporting results of power readings taken in a number of different mines in Illinois and other fields, 40 watt-hours per square foot was given as an average figure for cutting in the coal and the usual range in energy consumption, dependent upon hardness, was estimated at from 30 watt-hours to 55 watt-hours or higher. Results of three test runs made in mines of the Peabody Coal Company, operating in the Illinois No. 6 seam showed, as reported in that article, the following energy consumptions: Test No. 1—height of coal undercut, 7 ft. 0 in., energy consumed per ton, 0.19 kw-hr. and energy consumed per sq. ft. of area cut, 0.049 kw-hr.; Test No. 2—height of coal undercut, 7 ft. 6 in., 0.24 kw-hr. per ton, 0.066 kw-hr. per sq. ft.; Test No. 3—height of coal undercut, 7 ft. 6 in., 0.175 kw-hr. per ton, 0.0485 kw-hr. per sq. ft. Breast machines were used in the first two tests and a short-wall machine in the third. The cutter bits were sharp at the beginning of each test.

With few exceptions, the thickness of coal actually undercut varied within narrow limits—between 5½ and 8 ft.—so the average figure given for the group of 29 mines, 0.55 kw-hr. per ton of coal mined, which is approximately the same as the figure secured for most cases of cutting in 5 ft. coal, was considered sufficiently accurate to warrant its use (adjusted for seam thickness) in estimating the power requirements in mines for which no such figures are available.

*"Progress in Design of Mining Machines has greatly reduced the labor cost of cutting Kerf in coal." Coal Age, May 18, 1922.

24. *Electrical Energy Consumed by Haulage.*—The compilation of power statistics for mine haulage entails intricate calculation, even under the most favorable conditions. It is especially involved when the data are incomplete. If mine locomotives were of one standard type or of one standard weight, or if they all performed like duties under similar conditions, the study would be relatively simple. But with locomotives or various weights and of numerous types, even in a single mine, with little or no attempt at segregation of the power demands, the collection of useful information is extremely difficult. There are probably few mines in Illinois where exact individual locomotive performances are known in terms of energy consumption and ton-miles. Worse still, mine officials as a rule do not know their over-all haulage power requirements nor their costs.

In most Illinois coal mines, haulage is performed in two stages—gathering and main-line—and usually the locomotives are of different sizes and types for the two stages. If there were definite relations as to mileage between gathering and main haulage, or if certain locomotives were restricted exclusively to one or the other of these respective stages, relatively close estimates of energy per ton-mile of performance, or simply per ton of coal produced, might be made. During 1921, in a group of typical Illinois coal mines having complete locomotive haulage, the gathering locomotives averaged 4.8 miles of travel and 119 ton-miles of duty per day, while the main-line locomotives averaged 31.3 miles of travel and 1985 ton-miles of duty per day. The ton-mileages were therefore as 1 to 17.

It is not possible to obtain figures for the energy consumed by haulage in each of the mines that use locomotives. Of the 48 mines in question, data on total daily energy used in kilowatt-hours per ton of coal hauled are known for but 26 mines. The gross daily tonnage of these 26 mines is 82 745 or an average of 3182.5 tons per mine. In these mines there are 276 locomotives, this indicating an average daily tonnage per locomotive of 300 as compared with the figure of 290 for the 48 mines.

Two distinct systems of electric power transmission and utilization have been adapted to mine haulage practice and it is therefore possible to classify the machines into but two corresponding groups when studying their power demands. One class will include all locomotives that receive their power from trolley wires while the other class includes all locomotives operated by storage-batteries. Operators who have locomotives of both these classes generally keep separate records of the energy delivered to the trolley systems and to the charging stations respectively, whereas they have no knowledge as to how their trolley power is relatively appropriated by straight trolley locomotives in main haulage and by reel-and-trolley locomotives in gathering.

There are trolley locomotives in every one of the 26 mines and battery locomotives in 13 of them. The gross daily energy consumption of the 175 trolley locomotives is 40 288 kw-hr., an average per locomotive of 230 kw-hr. Similarly, the gross daily energy consumption of the 115 battery locomotives is 12 386 kw-hr., an average per locomotive of 107.70.

The effort to secure data on electric-haulage power requirements in terms of ton-miles has not furnished returns as satisfactory as those results which cover only total consumptions per mine or per machine. Power records of the desired sort are available for but 17 of these mines. In these 17 mines there are 63 straight trolley, 31 reel-and-trolley, 60 straight-battery, and 3 combination locomotives. The battery and combination locomotives operate in but 9 mines, each of which has an average daily production of more than 2600 tons. As a rule, battery service is installed only in up-to-date mines of fairly large output and is ordinarily used only for gathering; but there are numerous instances in which it is applied to main-line haulage as well. The following data from these 17 mines have been obtained for reasonably large numbers of locomotives in actual practice and therefore probably exemplify average performances. The 94 trolley and reel-and-trolley locomotives vary in energy consumption between 0.21 and 1.22 kw-hr. per ton-mile, the true or weighted average per machine being 0.45 kw-hr. per ton-mile. Similarly, the 60 straight-battery locomotives consume from 0.28 to 0.96 kw-hr. per ton-mile, their average being 0.56 kw.-hr. per ton-mile. The 3 combination locomotives consume, on the average, 0.50 kw-hr. per ton-mile.

A comparison of the relative energy consumption of trolley locomotives and of battery locomotives cannot justly be based upon these data because of the wide differences in their usual duties. It would appear, from these figures, that battery locomotives consume about 25 per cent more energy than do trolley locomotives, per average unit of service performed, but such a conclusion would be in error. The battery locomotives are used chiefly in gathering. Owing to the many handicaps, such as small trips, short hauls with frequent starting and stopping, bad grades in rooms, and poor track with many turns, gathering operations must inevitably consume more energy per ton per mile than does main-line haulage. While opinions of mine operators vary considerably upon this question, it is a significant fact that battery locomotives are being used increasingly in main haulage.

At one of the mines in Class D an accurate record of haulage power consumption was kept for the year 1919. Three trolley locomotives consumed almost exactly the same amount of energy as did twelve battery locomotives. The trolley units averaged 1624 ton-miles each day while the battery units averaged 119 ton-miles each. Their gross ton-mileages were therefore as 3.4 to 1. The reciprocal of this ratio indicates their relative energy consumptions per ton-mile and is greatly in favor of trolley haulage. However, when due weight is given to the unlike operating conditions, the discrepancy is largely explained. The average length of main-line haul was 3670 ft. while that of gathering was but 1000 ft.; and the numbers of cars per trip were, respectively, 13 and 7. The average energy used in haulage for the year was at the rate of 0.695 kw-hr. per ton of coal produced. This was divided nearly equally between the three trolley and the twelve battery locomotives, and therefore the consumption per machine per ton must have been approximately 0.12 kw-hr. by each trolley unit and 0.03 kw-hr. by each battery unit, or in the ratio of 4 to 1. This ratio compared with the ratio given for the ton-mileages would indicate a slight economic advantage in battery haulage. During the year 1921 the haulage power consumption per ton in this same mine was considerably reduced, notwithstanding longer main hauls, and this was attributed, in part, to the use of mixed trolley and battery locomotives on the main lines of haulage.

Statistics on haulage costs are given in Bulletin 132, Engineering Experiment Station, University of Illinois.* However, these statistics do not well cover power costs in themselves as separate from labor and total haulage costs.

25. *The Use of Alternating Current in Haulage.*—It was natural that the electrical power first used in coal mines should be direct current because at that time the series-wound direct-current motor was the only type of electric motor that afforded the speed characteristics required in the operation of most mining machinery, particularly locomotives. The electric energy used in mining was generated at the mine power plant, usually in comparatively small quantities. It was the common practice at that time to use direct current at isolated plants. Every

*"A Study of Coal Mine Haulage in Illinois," Univ. of Ill. Eng. Exp. Sta., Bul. 132, 1922.

mechanical operation about a coal mine can be performed with direct current, provided the current can be transmitted in sufficient amount to the operating centers; but as the mine workings spread and the transmission distances become greater, the line losses also increase until they become unduly expensive and eventually prohibitive.

To avoid this difficulty the power, in many cases, is now transmitted in the form of alternating current, at high voltage, over smaller conductors, to underground stations that are relatively near the working faces, where it is converted into direct current at the proper low voltage. In Illinois the maximum voltage which may lawfully be carried underground on bare wires or apparatus is 275, regardless of whether the current is direct or alternating.

Alternating current can be used to drive every kind of machinery in coal mines except locomotives, and the question arises, why is not this form of current used also in haulage? Its adoption for that purpose would vastly simplify the electric system of a mine, for in almost every electrified mine, under present practice, there are two complete sets of wiring. The large mines that are supplied with alternating current must have underground converting stations, simply to provide direct current to the locomotives. Alternating current is used with success in surface locomotive haulage, although the practice is not so common as it was a few years ago. This being the case, the question arises, why is alternating current not used in underground haulage? The reason is that certain features of standard electrical engineering practice oppose the use of alternating current in driving mine locomotives.

Most alternating-current generating equipment delivers three-phase current, usually of 60 cycles, and this is ordinarily the only form of power procurable from public-utility companies or mine power-plant a.c. generators. To transmit three-phase current, three conductors are necessary. In order to use three-phase alternating current in haulage, therefore, three trolleys would be required, or at least two trolleys with the rails acting as a third conductor. Live rails and trolley wires, even at low voltage, are big hazards and although it is possible to guard exposed trolley wires in a measure, two such wires are twice as dangerous as one wire. Another difficulty with three-phase current in haulage is the impedance of the circuit. Phase splitting has been suggested as a means of adapting three-phase current to haulage but it has not been found practicable to put the necessary additional apparatus upon the comparatively small mine locomotive.

The single-phase commutating type of motor, closely resembling a direct-current motor, is used in alternating-current locomotives. These motors are about 30 per cent heavier than direct-current motors of the same capacity. This feature in itself is not a serious objection but the further facts that they demand considerably more space and that they must be driven at speeds necessitating double-reduction gearing render these motors unsuitable for mine locomotives. Again, it appears that the single-phase motor is not as rugged as a direct-current motor, especially in withstanding excessive power loads applied when the machine is stationary. As this condition frequently occurs in mine-locomotive usage, the risk of short-circuiting and injury to armature windings is important. Another disadvantage is that more trolley copper is required for an alternating-current locomotive than for a direct-current locomotive delivering the same amount of power. This is because an alternating-current motor has a power factor considerably less than unity, so that, at a fixed voltage, the motor requires correspondingly greater current. It is found by experience also that the expense of upkeep is greater for single-phase motors than for direct-current motors.

The whole question was submitted to several of the leading American manufacturers of electrical mining machinery, and the consensus of their opinions is: first, that alternating-current locomotives for underground service are at present impracticable; second, that they will never become popular in competition with direct-current locomotives; and third, that alternating current will ultimately be used for every power requirement in coal mining other than haulage, but that direct current will always be required for this branch of the work.

26. *Electrical Energy Consumed by Hoisting.*—Electricity is used for hoisting at but five of the 50 mines. These five mines are those of Class G, in which electric power is used exclusively for the five major operations of coal mining. As a rule, mines of this class have a large daily coal production. Four of these mines hoist with cages, and one with skips.

The hoisting characteristics for the five mines of this class are: average tonnage per day, 3523; average number of hoists per day, 934; average number of tons per hoist, 3.77; average daily consumption of energy, 2460 kw-hr.; average consumption of energy per ton of coal hoisted, 0.698 kw-hr.

It seems well to analyze the data still further by segregating the four cage mines and calculating their average performances. The hoisting characteristics of these mines are: average tonnage per day, 3529 (about as above); average number of hoists per day, 1054; average number of tons per hoist, 3.35; average energy used daily, 2700 kw-hr.; average energy consumed per ton of coal hoisted, 0.765 kw-hr.

The skip mine has the following hoisting characteristics: daily tonnage, 3500; number of hoists daily, 457; tons of coal per hoist, 8.0; energy consumption per ton, 0.428 kw-hr. If it be permissible to make comparisons between cage hoisting and skip hoisting from these meagre data, it appears that, for approximately equal tonnages hoisted per day, there is a decided economic advantage in favor of skip hoisting. As these figures apply to these four very representative cage mines and one up-to-date skip mine, the energy consumed per ton in skip hoisting is but 56 per cent of that for cage hoisting. While there can be no doubt that skip hoisting is the more economical it is well to place little dependence upon the particular deduction here drawn, for in this instance the skip-hoisting distance is but 64 per cent of the average cage-hoisting distance.

Some power is consumed by hoisting even on idle days, strikes not considered. At the five mines having electric hoists the power used on idle days varied from one-eighteenth to one-third of the power consumption on producing days.

27. *Electrical Energy Consumed by Pumping.*—As stated previously, exactly one-half of the 50 selected mines use electric power for main pumping, but data for actual power demands in main pumping are obtainable for but 21 of the 25 mines. Gathering is done electrically in 35 mines.

In general the power required for gathering water to the main pump greatly exceeds the power consumed by the main pumps. Often the gathering pumps are at long distances from the main shaft, the pipelines are on up-grades and of small sizes, and the pumps themselves have been selected with little regard to their efficiency. The direct-current motors on these pumps are generally fed by long wiring with large resistance. Usually the duty of any individual gathering unit is erroneously deemed so small that its performance is delegated to out-of-date and inefficient equipment. On the other hand, the main pumps in some, not all, of these same mines are of modern, efficient types.

In the case of extensive old workings at comparatively shallow depth, the bulk of the water entering the mine is first collected at inbye sumps. The horizontal distances over which such water is handled are in some cases more than half a mile, and the pipe-lines are small and tortuous, while the lift at the main shaft is not only short but through a fairly adequate size of pipe. In one case of this sort the main pumps consume only 2.8 per cent of the total pumping power. From such an extreme case the relative amounts of electric power consumed by the two kinds of mine pumping vary until the other extreme is reached and the main pumps absorb all or practically all of the power.

The coal operator usually gives less heed to pumping than to any of his other mining activities. He knows nothing as to its cost when it is done by steam and very little more when electric power is used. In exceptional cases only have there been meter determinations of the energy used by even the main pumps. Data were collected for such pumping requirements at 16 mines. The quantity of water handled per kilowatt-hour varies from a minimum of 24 gallons to a maximum of 1400 gallons. This last figure is for a mine having an average daily flow of 84 000 gallons, a very low gathering load, and a vertical lift at the shaft of but 105 ft. The minimum accomplishment per kilowatt-hour, on the other hand, is for a mine of 375 ft. depth (about the average) and a daily flow of only 1200 gallons, this being the mine mentioned previously as consuming all but 2.8 per cent of its pumping power in gathering. If we eliminate these two extreme cases, the pumping in the remaining 41 typical mines is at the average rate of 638 gallons per kilowatt-hour.

28. *Proportional Distribution of the Total Power Consumption.*—Although complete power data could not be collected for all of the fifty-eight selected mines, sufficient data were obtained after much effort, to construct Table 2, covering fifty of these mines. These represent all of the classes specified in Chapter V and may be accepted as fairly representative of shaft mines in Illinois. At mines 17 and 36 the duties of the electric pumps are so small as to be negligible, and the power consumptions were not considered. The other blank spaces indicate either manual mining or mule haulage. At mine 5 mining is performed by compressed air produced in a steam-driven compressor. The figures in the six columns of percentages were derived according to the method described in Chapter VIII, except in the case of one wholly electrified mine (36) at which these data were obtained directly from meter records.

It should not be inferred that all of these power percentages stand for cost percentages as well. For mines at which steam is consumed for some activities and purchased electrical energy for all or part of other activities, the figures in this table mean little regarding relative power costs. Using these figures, however, it is possible to compute definitely the cost percentages for such cases if we have accurate data for the daily costs of steam generation and of purchased electrical power. There is often a wide difference between the cost of electric power generated at the mine and that of purchased electric power.

In the cases of mixed-power mines that generate all of their electric power, the energy percentages given in the table are also the respective cost percentages. Mines 4 and 6 (Class A) purchase and use electricity in relatively small amounts only for miscellaneous purposes, so that the energy percentages also closely represent the cost percentages. For Class G mines (22, 36, 37, 38, and 43) which use electric power only, the energy percentages may be taken as identical with the cost percentages, except for the slight error which might be introduced because of the steam consumed in heating buildings and wash-house water.

The figures in the Miscellaneous column in Table 2 do not include power used in operating coal-washing plants. It will be noted that these figures average about one-tenth of the total power and are generally but little affected by the scale of operations. The unusually high figures in this column of the table are explained by unusual conditions, such as heavy surface or boiler-feed pumping, carpenter and machine shops that serve other mines, or the crushing and screening of coal before shipment to washeries. Miscellaneous data include both steam and electric consumptions except in the cases of wholly electrified mines.

A study of the percentages in the table fails to reveal any consistent relationship between the six general items. Fluctuations in each column are wide. In the item of pumping this is to be expected, but when we note a range of from 1.4 per cent to 50.8 per cent in hoisting, of from 2.2 per cent to 61.9 per cent in ventilation, and of from 2.1 per cent to 51.0 per cent in haulage, we are ready to believe that each mine, indeed, has its individual power problem. There is not a single mine in this table whose percentages show any approach to agreement with general averages.

The geometric or weighted averages take into consideration the tonnages produced at each mine. The fifty mines are arranged according to their average daily productions and are then separated into five groups representing different scales of production.

TABLE 2

DISTRIBUTION OF ENERGY IN ILLINOIS COAL MINES

P—electric power purchased; M—electric power made by operator; s—steam; e—electric.

		Energy Consumption, Percentage of Total					
Mine No.	Daily Tonnage	Hoisting	Ventilation	Pumping	Mining	Haulage	Misc.
1	650 M	s 1.4	s 2.2	s 52.2	e 22.0	e 6.2	16.0
2	950 P	s 32.8	e 47.1	e 3.4	....	e 7.0	9.7
3	1010 P	s 18.4	s 61.9	e 0.5	....	e 14.0	5.2
4	1025 P	s 39.0	s 50.5	s 2.1	....	....	8.4
5	1200 M	s 10.7	s 20.3	s 0.5	* 41.5	e 20.7	6.4
6	1255 P	s 40.4	s 46.3	s 6.1	....	....	6.7
7	1500 M	s 13.8	s 55.9	s 2.9	....	e 23.2	4.3
8	1600 M	s 7.6	s 26.4	se 17.5	e 28.5	e 7.1	12.9
9	1750 P	s 19.7	e 31.6	e 6.7	....	e 34.9	7.1
10	1900 M	s 10.6	s 8.0	e 2.4	e 26.6	e 31.2	21.2
1-10	below 2000	– 19.5	– 35.0	– 9.4	– 29.6	– 18.2	9.7
11	2000 M	s 50.8	s 13.9	e 2.9	e 4.7	e 3.8	23.8
12	2000 M	s 23.4	s 27.1	se 23.4	e 2.5	e 2.1	21.7
13	2100 M	s 15.8	s 38.1	e 3.6	e 21.7	e 12.7	8.2
14	2200 M	s 6.3	s 36.7	s 3.3	e 33.4	e 10.1	10.1
15	2200 M	s 13.4	s 19.8	s 1.9	e 45.7	e 8.0	11.2
16	2200 M	s 12.6	s 29.3	e 2.6	e 37.0	e 9.8	8.8
17	2250 M	s 17.4	e 33.1	e	e	e 51.0	4.5
18	2445 M	s 17.5	s 33.1	e 1.1	e 32.8	e 10.4	5.1
19	2470 M	s 16.3	s 13.7	e 1.9	e 39.1	e 16.3	12.6
11-19	2000-2500	– 19.3	– 27.1	– 5.1	– 27.1	– 15.6	11.6
20	2500 M	s 19.8	s 28.6	s 0.2	e 23.6	e 19.3	8.6
21	2600 M	s 5.7	s 2.5	se 35.9	....	e 40.1	15.9
22	2635 M	e 32.7	e 21.8	e 2.2	e 29.1	e 10.2	4.0
23	2685 P	s 5.1	s 25.7	se 27.6	e 12.4	e 12.4	16.8
24	2700 M	s 13.2	s 18.7	se 18.4	e 8.6	e 29.3	11.8
25	2700 P	s 13.1	s 18.2	se 2.7	e 24.9	e 16.6	23.9
26	2700 M	s 19.9	e 27.7	e 0.6	e 15.5	e 31.7	4.7
27	2750 P	s 13.3	s 19.8	se 3.2	e 11.1	e 47.9	4.7
28	2750 M	s 9.4	s 30.8	e 0.4	e 17.7	e 30.8	10.8
20-28	2500-3000	– 14.7	– 21.5	– 10.1	– 17.9	– 27.2	11.2
29	3000 M	s 15.6	s 38.9	s 0.2	e 21.6	e 17.8	5.9
30	3000 M	s 9.2	s 17.3	s 0.1	e 34.0	e 32.3	7.2
31	3000 M	s 33.3	e 23.1	e 4.5	e 16.2	e 13.3	9.6
32	3000 M	s 15.6	e 32.8	e 0.5	e 13.1	e 31.5	6.5
33	3200 M	s 16.4	s 29.2	e 0.1	e 38.4	e 12.4	3.6
34	3200 M	s 7.2	s 31.7	e 16.6	e 15.0	e 20.1	9.4
35	3500 M	s 17.3	s 17.6	e 34.9	e 9.3	e 7.6	13.3
36	3500 P	e 16.2	e 15.6	e	e 12.3	e 43.3	12.6
37	3710 P	e 24.1	e 21.0	e 6.0	e 30.0	e 11.7	7.1
38	3770 P	e 24.5	e 19.4	e 1.0	e 30.6	e 18.4	6.1
29-38	3000-4000	– 17.9	– 24.7	– 9.1	– 22.1	– 20.8	8.1
39	4000 M	s 10.4	s 12.7	s 3.5	e 24.7	e 32.4	16.4
40	4000 M	s 13.6	s 26.4	s 0.3	e 19.8	e 30.7	9.3
41	4000 M	s 16.7	s 25.7	e 0.5	e 32.0	e 18.0	7.2
42	4000 M	s 17.1	s 17.9	e 0.8	e 43.8	e 6.2	14.2
43	4000 M	e 19.9	e 17.2	e 0.2	e 13.2	e 33.0	16.6
44	4160 M	s 13.8	s 14.1	s 0.2	e 20.7	e 41.1	10.1
45	4200 M	s 14.8	s 13.4	s 4.9	e 26.1	e 23.2	17.7
46	4200 M	s 15.3	s 28.6	e 2.9	e 14.6	e 34.3	4.3
47	4375 M	s 15.3	s 9.1	s 0.1	e 26.9	e 38.6	10.1
48	4730 M	s 13.9	s 14.6	s 0.2	e 18.0	e 37.9	15.4
49	4910 M	s 16.0	s 14.2	s 0.2	e 19.5	e 41.1	9.0
50	5200 M	s 34.5	e 14.9	e 0.2	e 14.9	e 27.7	7.8
39-50	over 4000	– 16.8	– 17.4	– 1.2	– 22.8	– 30.4	11.5
Simple Averages ..		17.5	24.9	6.3	23.2	22.2	11.9
Weighted Averages		17.3	22.2	5.0	24.1	26.2	10.5
Probable General Averages		17.2	22.2	5.0	22.1	23.0	10.5

*Coal cutting is with punchers, the compressed air for which is produced by direct use of steam.

A significant feature of these average percentages is that mining, haulage, and ventilation consume nearly equal amounts of energy, aggregating two-thirds of the total.

The grouping of the mines shows that the scale of production bears no relation to the distribution of power to the major activities. Within each group are wide fluctuations in the percentages of energy consumed in each of the operations. The averages for each group show no resemblance to the percentages for any one mine in the group. There is also no consistent relationship between the five group averages. The variations appear least erratic for the last group whose mines have daily productions of 4000 tons and upward but in this group the average percentages of power do not tally, even approximately, with the percentages of any of the mines therein. The averages for the fourth group—mines whose daily outputs range between 3000 and 4000 tons—show the greatest similarity to the Probable General Averages.

Owing to the erratic features disclosed by Table 2, the same fifty mines were tabulated according to the classification explained in Chapter V, to ascertain whether or not mines that are operated with similar power arrangements will compare closely in the several power demands. Table 3 is the result in condensed form. The average daily productions of the mines in the several classes vary somewhat from the averages stated in Chapter V because this table contains data on only fifty mines instead of fifty-eight. The findings of Table 3 are about as indefinite as those of Table 2. The general average power consumptions for the 50 mines remain as in Table 2 but they do not resemble the average for any single class of mines.

Table 3 proves that mines may be operated under like systems of power and still be quite unlike in their power demands for the different activities. Due consideration of the many variable factors that affect power consumptions, even among mines utilizing the same forms of power for the same functions, lends credibility to the oft-repeated assertion that, in power matters, each mine is a problem in itself.

During the construction of these tables interesting statistical data were developed. In Table 2 there are spaces for power percentages covering 300 items, including 50 Miscellaneous items that include both steam and electrical power consumptions. Ten spaces represent operations performed by men or animals and hence contain no figures; two spaces are for power consumed (by pumping) in such insignificant amounts as to be negligible; 157 of the items involve electricity and 131 steam.

TABLE 3

PERCENTAGE OF ENERGY CONSUMPTIONS ACCORDING TO MINE CLASSIFICATIONS

MINES	A	B	C	D	E	F	G
Number of Mines	2	4	19	13	3	4	5
Production percentage	1.6	5.0	40.7	26.9	3.5	9.8	12.5
Tonnage, average	1140	1778	3014	2920	1650	3475	3523
Tonnage, lowest	1056	1010	650	1900	950	2700	2635
Tonnage, highest	1255	2600	4910	4200	2250	5200	4000

Percentages of total for the mines s—steam e—electricity

Averages are weighted for tonnage

	A	B	C	D	E	F	G
Hoisting, average	s40.0	s14.2	s12.8	s16.6	s17.1	s27.3	e22.9
Hoisting, lowest	39.0	5.8	1.4	7.2	8.2	19.9	16.0
Hoisting, highest	40.4	18.4	19.8	50.8	32.8	34.5	32.7
Ventilation, average	s48.2	s29.3	s19.3	s24.0	e29.4	e23.0	e18.8
Ventilation, lowest	46.3	2.5	2.2	8.0	20.2	14.9	15.7
Ventilation, highest	50.5	61.9	38.9	38.1	47.1	32.8	21.8
Pumping, average	s 4.3	s20.6(a)	s 4.4(a)	e 5.9	e 3.1	e 1.3	e 1.9
Pumping, lowest	2.1	0.5	0.1	0.1	0.0	0.2	0.0
Pumping, highest	6.1	36.7	52.2	34.9	6.8	4.5	6.0
Mining, average			e23.0 (b)	e26.2		e13.5	e22.7
Mining, lowest	hand	hand	8.6	8.6	hand	13.1	12.4
Mining, highest			45.7	43.8		15.5	30.6
Haulage, average		e23.1	e28.7	e17.1	e44.3	e27.6	e24.0
Haulage, lowest	mule	4.6	6.2	6.2	7.0	19.9(c)	10.2
Haulage, highest		40.9	47.9	37.3	67.1	31.7	43.3
Miscellaneous, average	7.5	12.8	11.8	10.2	6.1	7.3	9.7
Miscellaneous, lowest	6.7	4.0	4.7	3.6	4.5	4.7	4.0
Miscellaneous, highest	8.4	21.7	23.9	23.8	9.7	9.6	16.6

All miscellaneous figures include both steam and electricity.
Heavy line separates steam and electric operations.
(a) Some of these mines gather with electric pumps.
(b) At Mine 5 mining is by compressed air, generated by steam power. (See Table 4.) Placed in Class C as nearest.
(c) Estimated for Mine 31 (See Table 4).

In other words, steam at present handles 43.7 per cent of the mining activities and electricity 52.3 per cent. This percentage refers to the mining activities numerically without regard to their magnitude.

When proper consumptions of steam and electricity are assigned to the Miscellaneous column, steam is found to account for 2104 out of a total of 5000 percentage units (50 mines × 100 per cent) and electricity for 2896. As this calculation does not include manual or animal performances these figures indicate that steam performs 42 per cent of the mechanical duties about these mines and electricity the balance. The preceding calculation (as explained) covered only the relative numbers of duties performed by the two forms of power, but this last calculation deals with actual energy consumptions, and therefore approximately 58 per cent of all the energy at these fifty mines is electric. This one finding is, in itself, significant and of practical value. The comparatively close check between the two sets of calculations is also valuable in that it proves that there is little difference between the average magnitudes of the duties assigned to these different kinds of power. A third feature not disclosed by the tables but brought out by the calculations is that steam performs 53 per cent of the Miscellaneous functions, and electricity 47 per cent. This also indicates the nearly equal footing of the two forms of power.

VIII. Power Requirements at Mixed-Power Mines

29. *The Distribution of Power.*—A majority of the coal mines in Illinois operate with both steam and electrical machinery. The selected mines in all classes except A and G (see Chapter V) may be said to operate with *mixed power*.

At some of these mixed-power mines part or all of the required electric energy is generated in the local power houses. At each of the other mines part or all of it is purchased from a utility company or is received from a neighboring commonly-owned mine. When electric energy is thus received at a mine from an outside source it is metered, and its cost and amount may be easily computed; but when it is generated locally through the use of steam drawn from boiler plants that are simultaneously supplying power to hoisting engines, fan engines, and pumps, there is no simple or accurate method of segregating the costs of power consumed, on the one hand as live steam, and on the other hand as electricity. Further, in either case, there is no allocation of the consumptions of either electricity or steam to the different major activities.

At but few mines in the state are there any accurate data covering the distribution of total power costs to the ultimate consumptions. In fact it is only at wholly electrified mines that itemized power costs are assigned to such separate consumptions, and even then it is done only approximately. At one prominent mine of this type careful meter records covering a 12-months period from April, 1921 to March, 1922* inclusive show a distribution of power consumptions as follows: mining, 12.4 per cent; haulage, 43.3 per cent; hoisting, 16.0 per cent; ventilation,

*Eugene McAuliffe, "Records at Kathleen Mine show that when running-time is halved, power costs per ton mined are doubled," Coal Age, May 18, 1922, p. 17.

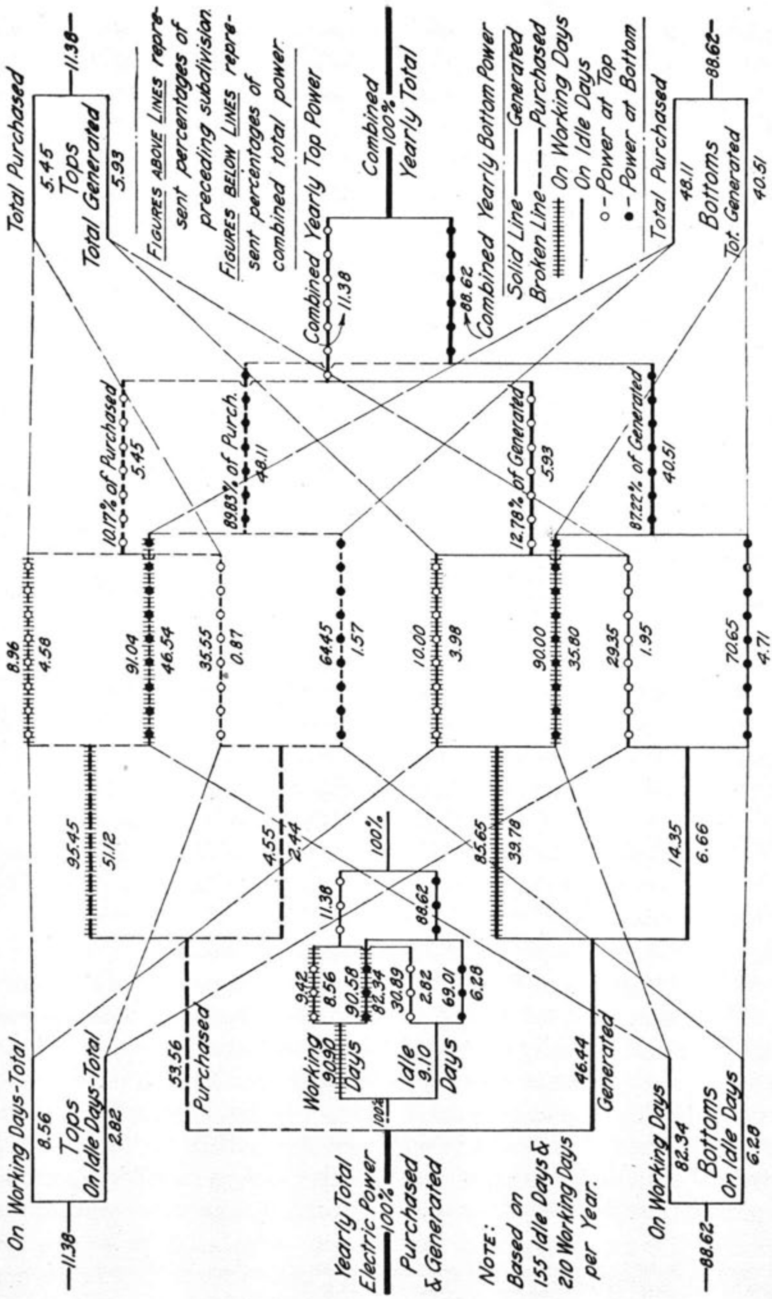

Fig. 1. Mine Power-Distribution Diagram

15.7 per cent; tipple, 4.4 per cent; miscellaneous, 2.1 per cent. The transmission and transformer losses amounted to the remaining 6.1 per cent of the total power purchased. It is not to be expected that any other coal mine would show an allotment of its total power consumption in exactly these proportions.

If all operators were able thus to apportion their power requirements they would be in position to locate leaks, inefficiencies, or other abnormal operating conditions that often might be remedied, with a substantial lessening of total mining costs. However, at present it seems, as already remarked, that such a segregation is possible in a practical way only at wholly electrified mines.

This single phase of the power question persists in the economics of coal mining. While it has given the more progressive operators some concern, it has become an accepted condition to such universal extent that inquiries regarding cost segregation at mines using mixed power have been regarded, sometimes, as lacking serious import. There are still coal operators in Illinois who care very little for details in cost accounting. Some such men consider it almost superfluous to separate costs into such primary heads as labor, power, and materials.

It would seem that, when using power in a form that is so conveniently measurable as electric current, consumers would feel sufficient interest to warrant the installation of meters wherever useful; and yet there are many mines at which not the least attempt is made to segregate even the electrical power consumed underground from that consumed on top. At other mines this single differentiation of electric-power consumption prevails but no effort is made to allot the power to its ultimate points of consumption, that is, to the places where it performs useful work. Thus, while the undercutting, haulage, ventilation, pumping, and illumination of a mine may be electrical, there is no record as to how the various demands absorb the power. Figure 1 is a diagramatic scheme followed by one large company in segregating its generated and purchased electrical power into the consumptions on top and in the mine. This shows what may be accomplished by systematic cost accounting. Allocation of the total power consumption to working-day and idle-day accounts is particularly enlightening. This depends, in any case, upon the steadiness of operation, expressed in this case by the relative numbers of working days and idle days in the year, which were 200 and 165, respectively.

When it comes to the segregation of steam consumptions a real physical obstacle is encountered. Although flow-meters are advertised to measure accurately volumes of traveling gases, none has been found that will measure live steam acceptably as it is used around mines, and hence operators have ceased to consider them favorably. In steam hoisting the extreme fluctuations in demand for power bring about a rapidly fluctuating rate of flow for which meters are not designed. Steam pressure, temperature, and velocity change frequently, abruptly, and widely, in a manner quite unknown in other types of industrial plants. As a consequence there is no measurement of live steam about the Illinois coal mines and hence there is no physical way of closely determining how the output of the boilers is consumed.

30. *A Scheme for Theoretical Segregation.*—During the study of this phase of the mixed-power question, there was conceived a scheme for obtaining a fairly accurate segregation of the total steam consumption into the major activities. The authors can learn of no instance in which the scheme has previously been applied at a coal-mine plant. In principle it is simple. The results are not presumed to be more than approximately correct, but it is assumed that even an approximate method will prove useful to many progressive operators.

No machine ever delivers, as useful work, all of the energy that it receives; hence we are accustomed to consider the efficiencies of all kinds of machines. When, as is the case at a mixed-power mine, energy passes step by step from one machine to another in series, each time undergoing a metamorphosis, much of it is dissipated by leakage, friction, resistance, heating, and inductance. Of the usable energy in a specific quantity of live steam in the boiler room, perhaps less than 25 per cent will be delivered as useful work in, say, pumping mine water. If this energy is first utilized to operate a steam engine driving an electric generator (dynamo), the current from which is transmitted into the mine and there caused to operate a motor which, through gearing, drives a pump whose actual displacement is only 60 per cent, there will be so many opportunities for power waste that the figure given above is not at all out of reason. In many actual pumping installations the efficiency does not reach 25 per cent.

To apply the suggested scheme it is necessary to determine fairly accurately the amounts of power actually delivered at the ultimate points of each branch of mining operation. In other words, figures should be had for the power really delivered as work in cutting, haulage, pumping, hoisting, and ventilation. The derivation of these essential data is generally far from easy.

For some of the mechanical operations in coal mining, an engineer might utilize accepted text-book data in estimating these deliveries of power. The theoretical amounts of power used in the major branches will be direct functions of certain measurable items: in hoisting—tonnage and depth of shaft; in pumping—quantity of water and distances the water is moved both horizontally and vertically; in haulage—tonnage and distances; in ventilation—volume of air and pressure at airshaft; in mining—square feet of cutting. Numerous other items influence the results, such as, in the case of hoisting, the frictional resistances in cables and cage guides or, in the case of pumping, the resistances of pipe-lines. There are many other and indeterminate factors involved in each of these calculations. There are sometimes opportunities, especially in cases of electrically operated machines, such as cutters, to meter the power delivered to such machines. While such measurements will not represent the work delivered by the machines, they afford essential data.

It is next necessary to trace each such amount of power back along its route to the boiler room, making proper increments at each transformation and for every kind of loss.

In measuring power about mixed-power plants, two kinds of units are universally used—horsepower and kilowatts—but to apply this scheme it will be necessary to confine our measurements to one unit and, for obvious reasons, the authors adhere to horsepower. All ultimate energy deliveries, therefore, must be computed in horsepower-hours and the figures for boiler-room power supply must be in similar units. In this discussion the energy supplied by the boilers will be conceived as *steam horsepower-hours* or *steam power-units*, but these must not be confused with boiler horsepower-hours.

When we have thus derived the units of steam power demanded daily by each of the branches of mining, we can add the several results together to obtain the gross requirements of the boiler plant. If we then also have data from which to calculate the daily cost of the labor, fuel, water, supplies, and various overheads absorbed in the operation of the power plant, the apportionment of the costs to the separate consumptions is comparatively simple.

This scheme is an attempt to do mathematically what is impossible mechanically or physically. It involves chances of error in the assignment of efficiencies to mechanical units of all sorts and to transmission units such as pipes and wires. However, every experienced superintendent or engineer should be able to assume reasonable efficiencies for all of the equipment about his mine. He will feel well repaid for his effort in following out this scheme of analyzing the gross power cost in its application to his particular conditions, especially when using mixed power.

Many of the power consumption figures given in this publication were obtained wholly or in part by this method. In many cases, power readings on some of the factors entering into the estimates were available and therefore few assumptions were necessary. All of the basic data that could be secured were used in each case, and where efficiencies and unit power consumptions were unavoidably assumed, the individual operating conditions were taken into consideration to the best of the authors' ability. For these reasons, the following general formulas may be properly applied to any individual case only by rational adjustment of the various efficiency numbers to suit the conditions. The operating engineer, in applying this method of estimation to his own power distribution problems can, from intimate knowledge of his own equipment, fix these assumed efficiencies and unit consumptions more accurately than the authors have been able to do herein.

The general formulas for the daily consumption of power as electricity in steam horsepower-hours by the five major activities are as follows:

$$\text{Hoisting: } \frac{\text{daily tonnage} \times 2000 \times \text{hoisting depth (feet)} \times \text{s}}{33\ 000 \times 60 \times e \times h}$$

$$\text{Ventilation: } \frac{w\text{-}g \times 5.2 \times q \times 24}{33\ 000 \times f \times e \times h}$$

$$\text{Main Pumping: } \frac{\text{Gal. per day} \times 8.3 \times \text{depth} \times r}{60 \times 33\ 000 \times p \times e \times h}$$

$$\text{Cutting: } \frac{\text{number machines} \times \text{operating time (hours)} \times kw \times 1.34}{h \times t}$$

$$\text{or: } \frac{\text{daily tonnage} \times 0.55 \times 1.34}{24 \times h \times t \times \text{coal thickness (feet)}}$$

$$\text{Haulage: } \frac{w \times 2000 \times v \times \text{operating time (hours)}}{d \times 33\ 000 \times e \times t \times h}$$

Where s = shaft resistance factor (1.05)

e = mechanical efficiency of motor (0.85-0.87)

h = mechanical efficiency of engine generator sets (0.82-0.85)

$w\text{-}g$ = water-gage reading at air shaft

q = quantity of air circulated in cu. ft. per min.

f = fan efficiency (0.50-0.70)

p = pump displacement, percentage of theoretical (60)

t = transmission efficiency (0.75-0.95)

w = weight of locomotives in tons

r = water-pipe resistance factor

v = average speed in ft. per min. (main haulage, 4 mi. per hr. = 352 ft. per min.; gathering, 3 mi. per hr. = 264 ft. per. min.)

d = draw-bar pull, as fraction of locomotive weight (about 1/9 on main haulage)

0.55 = assumed power consumption kw-hr. per ton, in cutting 5-ft. seam.

1.34 = conversion factor kw. to h.p.

These formulas are for estimation of power consumptions where the driving units are direct-current motors supplied with electrical energy by engine-generator sets in the power house. In case alternating current is used, additional factors that may be required in the denominators of these expressions are motor-generator set efficiencies (0.82-0.85), transformer efficiencies (0.95-0.98), and rotary-convertor efficiencies (0.90-0.97).

In the cases of hoisting, ventilating, or pumping with steam-driven units, e in the formulas would stand for the engine efficiency while h would be omitted, and allowance would be made for the condensation and leakage losses in steam lines.

It may be well to call attention to the fact that the foregoing scheme avoids any consideration of boiler-plant efficiencies. The demands of the several activities in and about a mine are traced back to the boilers and there integrated and equated to the actual cost of operating the boiler plant. This being done, it is a simple matter to pro-rate this expense among the several activities.

By way of experimenting with this scheme, numerous mixed-power mines were studied. These were mines for which the operators had no knowledge regarding the relative consumptions of power by the several

TABLE 4

CHARACTERISTICS OF MIXED-POWER MINES USING STEAM AND GENERATED ELECTRIC POWER

Class	Number of Mine	Daily Production Tons	Hoisting Depth	Cost of Fuel at $2.40 Per Ton	Boiler Room Labor	Boiler Room Maintenance Overhead	Total Daily Cost of Steam, Dollars	Steam Hoisting St. H. P.-Hr. @ 85% Eff.	Electric Hoisting St. H. P.-Hr. @ 85% Eff.	Fan Engine St. H. P.-Hr. @ 81% Eff.
C	1	650	181	60.00	21.00	6.00	87.00	147	....	237
A	4	1025	470	36.00	28.60	22.00	86.60	602	....	780
C	5	1000	469	96.00	49.97	12.00	157.97	702	....	1333
A	6	1255	506	36.00	28.60	22.00	86.60	794	....	900
B	7	1500	234	26.70	22.50	5.75	54.95	438	....	1776
C	8	1600	149	33.60	26.00	10.00	69.60	297	....	1037
D	11	2000	696	237.60	92.96	8.79	339.35	2480	....	681
B	12	2000	297	261.60	99.57	18.49	379.66	741	....	859
D	13	2100	543	48.00	95.00	121.00	264.00	1424	....	3443
C	14	2200	154	99.20	61.75	12.00	172.95	423	....	2519
C	15	2200	256	62.40	35.86	3.26	101.52	703	....	1037
D	16	2200	324	84.00	38.50	15.00	137.50	889	....	2074
D	18	2445	461	75.00	37.00	18.00	130.00	1408	....	2667
D	19	2470	266	72.00	100.00	77.50	249.50	819	....	689
C	20	2500	349	266.40	164.90	20.36	451.66	1089	....	1570
B	21	2600	189	96.00	29.00	11.00	136.00	613	....	267
C	24	2700	369	72.00	22.00	8.00	102.00	1243	....	1778
F	26	2700	689	93.60	66.00	12.10	171.70	2154	....	....
D	28	2750	349	72.00	30.00	30.00	132.00	1029	....	3351
C	29	3000	349	292.80	109.06	11.45	413.31	1364	....	3407
C	30	3000	255	160.20	49.97	22.00	232.17	995	....	1867
F	31	3000	687	346.80	131.77	84.64	563.21	2537	....	....
F	32	3000	574	84.00	50.36	10.15	144.51	2000	....	....
D	33	3200	499	144.00	60.00	22.50	226.50	1992	....	3556
D	34	3200	159	129.60	42.72	12.00	184.32	635	....	2815
D	35	3500	234	327.60	90.71	51.07	469.38	1022	....	1037
C	39	4000	333	240.00	85.00	14.00	339.00	1662	....	2014
C	40	4000	413	72.00	36.00	9.00	117.00	1828	....	3600
D	41	4000	375	247.20	68.13	12.00	327.33	1872	....	2874
D	42	4000	409	156.00	.....	.....	266.00	2041	....	2133
G	43	4000	650	264.00	100.00	30.00	394.00	....	3660	....
C	44	4160	387	132.00	.....	.....	218.16	1755	....	1800
C	45	4200	424	168.00	72.00	12.00	252.00	2222	....	2014
D	46	4200	509	172.80	90.41	14.63	277.84	2410	....	4500
C	47	4375	363	158.00	.....	.....	261.13	1715	....	1024
C	48	4730	370	144.00	.....	.....	237.99	1894	....	1990
C	49	4910	396	132.00	.....	.....	218.16	2145	....	1902
F	50	5200	699	144.00	.....	.....	469.14	4535	....	....
D	57	3300	469	172.80	75.00	15.00	262.80	1931	....	2824
D	58	6000	563	180.00	144.63	46.55	371.18	4215		4740
Total........		121070	16068		2254.97	800.24	9555.69			
No. of Mines.		40	40		34	34	40			
Average.....		3026.7	401.7		66.32	23.54	238.89			

TABLE 4 (CONTINUED)
CHARACTERISTICS OF MIXED-POWER MINES USING STEAM AND GENERATED ELECTRIC POWER

Class	Number of Mine	Fan Motor St. H. P.-Hr. @ 85% Eff.	Steam Pumping St. H. P.-Hr. @ 49% Eff.	Electric Pumping St. H. P.-Hr. @ 51% Eff.	Mining St. H. P.-Hr.	Haulage St. H. P.-Hr.	Miscellaneous for 24 Hrs. As Steam—St. H. P.-Hr.	Miscellaneous for 24 Hrs. As Electricity St. H. P.-Hr.	Total St. H. P.-Hr. Per Day As Steam	Total St. H. P.-Hr. Per Day As Electricity
C	1		5472	225	2402	678	1503	242	7359	3547
A	4	....	33	....	....	....	90	40	1505	40
C	5	....	34	....	2720	1356	376	41	2445	4117
A	6	....	118	....	....	....	90	40	1902	40
B	7	....	91	....	....	736	125	11	3166	11
C	8	....	270	418	1120	278	195	313	1799	2129
D	11	....	....	143	417		50	1114	3211	1674
B	12	....	318	421	145		146	542	2064	1108
D	13	....	....	328	1961	1145	215	527	5082	3961
C	14	....	91	137	2296	695	315	379	3348	3507
C	15	....	98	....	2389	417	225	362	2063	3168
D	16	....	....	183	2615	690	111	513	3074	4001
D	18	....	....	82	2647	842	55	358	4130	3929
D	19	....	....	98	1961	817	185	449	1693	3325
C	20	....	10	....	2354		139	334	2808	2688
B	21	....	2352	1550	....	4316	1002	718	4207	6584
C	24	....	1087	654	817	2779	719	402	4827	4652
F	26	3000	....	60	1683	3434	15	490	2169	8667
D	28	....	....	45	1920	3350	230	941	4600	6256
C	29	....	16	....	3447		165	358	4952	3805
C	30	....	16	....	3678	3490	587	189	3465	7357
F	31	1756	....	339	2245		106	625	2643	4965
F	32	4200	....	57	1683	4040	20	810	2020	10790
D	33	....	....	9	4682	1507	308	130	5856	6328
D	34	....	....	1471	1330	1785	183	653	3633	5239
D	35	....	....	2059	993		156	627	2215	3679
C	39	....	553	....	3922	5150	1306	1307	5535	10379
C	40	....	35	....	2692	4196	570	704	6033	7592
D	41	....	....	51	3582	2022	183	622	4929	6277
D	42	....	....	98	5229	734	197	1502	4371	7563
G	43	3150	....	35	2416	6070	22	3020	22	18351
C	44	....	26	....	2630	5230	230	1059	3811	8919
C	45	....	728	....	3922	3482	1262	1395	6226	8799
D	46	....	....	458	2305	5400	20	660	6930	8823
C	47	....	6	....	3024	4340	37	1100	2782	8464
C	48	....	25	....	2455	5175	234	1868	4143	9498
C	49	....	26	....	2615	5510	210	999	4283	9124
F	50	1962	....	21	1962	3641	32	993	4567	8579
D	57	....	....	196	4609	3808	211	785	4966	9398
D	58	....	....	2000	8420		....	1524	8955	11944
Total										
No. of Mines										
Average										

TABLE 4 (CONTINUED)
CHARACTERISTICS OF MIXED-POWER MINES USING STEAM AND GENERATED ELECTRIC POWER

Class	Number of Mine	Total Daily Power Consumption—St. H.P-Hr.	Cost in Cents Per St. H. P.-Hr.	Cost of Steam Per Day Consumed as Live Steam—Dollars	Cost of Steam Per Ton Consumed as Live Steam—Cents	Cost of Electricity Per Day—Dollars	Cost of Electricity Per Ton—Cents	Total Daily Power Cost—Cents Per Ton	Cost of Hoisting—Cents Per Ton	Cost of Ventilation—Cents Per Ton
C	1	10906	0.79773	58.70	9.031	28.30	4.354	13.385	0.180	0.291
A	4	1545	5.60518	84.36	8.230	2.24	0.219	8.449	3.292	4.265
C	5	6562	2.40734	141.60	11.800	16.37	1.364	13.164	1.408	2.674
A	6	1924	4.45932	84.82	6.758	1.78	0.142	6.900	2.821	3.198
B	7	3177	1.72962	54.76	3.650	0.19	0.013	3.663	0.505	2.048
C	8	3928	1.77189	31.88	1.992	37.72	2.358	4.350	0.329	1.148
D	11	4885	6.94677	223.06	11.153	116.29	5.815	16.968	8.614	2.365
B	12	3172	11.96910	247.04	12.352	132.62	6.631	18.983	4.435	5.141
D	13	9043	2.91938	148.36	7.065	115.64	5.506	12.571	1.980	4.786
C	14	6855	2.52297	84.47	3.839	88.48	4.022	7.861	0.494	2.886
C	15	5231	1.94074	40.04	1.820	61.48	2.795	4.615	0.620	0.915
D	16	7075	1.94346	59.74	2.716	77.76	3.534	6.250	0.785	1.832
D	18	8059	1.61310	66.62	2.725	63.38	2.592	5.317	0.927	1.758
D	19	5018	4.92210	84.18	3.408	165.32	6.693	10.101	1.649	1.387
C	20	5496	8.21798	230.76	9.230	220.90	8.836	18.066	3.579	5.161
B	21	10791	1.26031	53.02	2.039	82.98	3.192	5.231	0.297	0.129
C	24	9479	1.07606	51.94	1.924	50.06	1.854	3.778	0.497	0.708
F	26	10836	1.58453	34.37	1.273	137.33	5.086	6.359	1.264	1.761
D	28	10856	1.21592	55.93	2.034	76.07	2.766	4.800	0.452	1.481
C	29	8757	4.71977	233.72	7.791	179.59	5.986	13.777	2.146	5.360
C	30	10822	2.14535	74.34	2.478	157.83	5.261	7.739	0.712	1.335
F	31	7608	7.40287	195.66	6.522	367.55	12.252	18.774	6.260	4.333
F	32	12810	1.12810	22.79	0.760	121.72	4.057	4.817	0.752	1.579
D	33	12184	1.85900	108.86	3.402	117.64	3.676	7.078	1.157	2.066
D	34	8872	2.07755	75.48	2.359	108.84	3.401	5.760	0.412	1.827
D	35	5894	7.96369	176.40	5.040	292.98	8.371	13.411	2.325	2.360
C	39	15914	2.13020	117.91	2.948	221.09	5.527	8.475	0.885	1.072
C	40	13625	0.85872	51.81	1.295	65.19	1.630	2.925	0.392	0.773
D	41	11206	2.92102	143.98	3.599	183.35	4.584	8.183	1.367	2.099
D	42	11934	2.22893	97.43	2.436	168.57	4.214	6.650	1.137	1.190
G	43	18373	2.14445	0.47	0.012	393.53	9.838	9.850	1.962	1.689
C	44	12730	1.71375	65.31	1.570	152.85	3.674	5.244	0.723	0.741
C	45	15025	1.67720	104.42	2.486	147.58	3.514	6.000	0.887	0.805
D	46	15733	1.76373	122.22	2.910	155.62	3.705	6.615	1.012	1.889
C	47	11246	2.32198	64.60	1.476	196.53	4.492	5.968	0.910	0.543
C	48	13641	1.74467	72.28	1.528	165.71	3.503	5.031	0.699	0.743
C	49	13407	1.62721	69.69	1.419	148.47	3.024	4.443	0.711	0.630
F	50	13146	3.568	162.96	3.133	306.09	5.886	9.023	3.112	1.347
D	57	14364	1.82957	90.86	2.753	171.94	5.210	7.963	1.070	1.565
D	58	20899	1.77607	159.05	2.651	212.13	3.535	6.186	1.248	1.403
Total.......					161.607		173.112	334.723	64.012	79.275
No. of Mines.					40		40	40	40	40
Average					4.040		4.328	8.368	1.600	1.982

TABLE 4 (CONTINUED)

CHARACTERISTICS OF MIXED-POWER MINES USING STEAM AND GENERATED ELECTRIC POWER

Class	Number of Mine	Cost of Pumping—Cents Per Ton	Cost of Mining—Cents Per Ton	Cost of Haulage—Cents Per Ton	Cost of Miscellaneous—Cents Per Ton	Distribution of Power as to Use—Per Cent					
						Hoisting	Ventilation	Pumping	Mining	Haulage	Miscellaneous
C	1	6.992	2.948	0.832	2.142	1.35	2.17	52.24	22.01	6.22	16.01
A	4	0.181	.....	.....	0.711	38.96	50.48	2.14	.....	.....	8.42
C	5	0.068	5.457	2.720	0.837	10.70	20.31	0.52	41.45	20.66	6.36
A	6	0.419	.....	.....	0.462	40.88	46.35	6.07	.....	.....	6.70
B	7	0.105	.....	0.848	0.157	13.79	55.91	2.87	.....	23.15	4.28
C	8	0.762	1.240	0.308	0.563	7.56	26.39	17.52	28.51	7.08	12.94
D	11	0.497	0.797	0.652	4.043	50.77	13.94	2.93	4.70	3.84	23.82
B	12	4.422	0.477	0.391	4.117	23.36	27.08	23.29	2.52	2.06	21.69
D	13	0.455	2.726	1.592	1.031	15.75	38.07	3.62	21.69	12.67	8.20
C	14	0.260	2.632	0.795	0.794	6.17	36.75	3.33	33.49	10.14	10.12
C	15	0.087	2.107	0.368	0.518	13.43	19.83	1.89	45.66	7.97	11.22
D	16	0.162	2.310	0.610	0.551	12.56	29.31	2.59	36.96	9.76	8.82
D	18	0.060	1.745	0.554	0.273	17.43	33.08	1.12	32.81	10.43	5.13
D	19	0.197	3.947	1.645	1.276	16.33	13.73	1.95	39.07	16.29	12.63
C	20	0.033	4.258	3.480	1.555	19.81	28.57	0.18	23.57	19.26	8.61
B	21	1.879	.....	2.093	0.833	5.68	2.47	35.92	.....	40.01	15.92
C	24	0.694	0.325	1.107	0.447	13.16	18.74	18.37	8.60	29.30	11.83
F	26	0.035	0.988	2.015	0.296	19.88	27.69	0.55	15.54	31.69	4.65
D	28	0.019	0.849	1.481	0.518	9.42	30.85	0.40	17.69	30.85	10.79
C	29	0.025	2.984	2.439	0.823	15.57	38.90	0.18	21.55	17.80	5.97
C	30	0.011	2.630	2.496	0.555	9.20	17.25	0.14	33.99	32.25	7.17
F	31	0.837	3.049	2.491	1.804	33.34	23.08	4.46	16.24	13.27	9.61
F	32	0.022	0.633	1.519	0.312	15.61	32.78	0.46	13.14	31.53	6.48
D	33	0.005	2.720	0.875	0.255	16.35	29.19	0.07	38.43	12.36	3.60
D	34	0.955	0.864	1.159	0.543	7.15	31.72	16.58	15.00	20.12	9.43
D	35	4.685	1.243	1.016	1.782	17.34	17.60	34.93	9.27	7.57	13.29
C	39	0.295	2.089	2.743	1.391	10.44	12.65	3.48	24.65	32.37	16.41
C	40	0.008	0.578	0.901	0.273	13.56	26.42	0.26	19.75	30.70	9.32
D	41	0.037	2.616	1.476	0.588	16.71	25.65	0.45	31.97	18.04	7.18
D	42	0.054	2.914	0.409	0.947	17.09	17.89	0.81	43.81	6.15	14.24
G	43	0.019	1.295	3.254	1.631	19.92	17.15	0.19	13.15	33.03	16.56
C	44	0.011	1.083	2.154	0.532	13.79	14.13	0.21	20.65	41.08	10.14
C	45	0.291	1.566	1.390	1.061	14.78	13.42	4.85	26.10	23.17	17.68
D	46	0.192	0.968	2.268	0.286	15.30	28.56	2.90	14.63	34.29	4.32
C	47	0.003	1.605	2.304	0.603	15.25	9.10	0.05	26.89	38.61	10.10
C	48	0.009	0.905	1.909	0.775	13.89	14.59	0.18	17.98	37.95	15.41
C	49	0.009	0.867	1.826	0.400	16.00	14.18	0.20	19.51	41.10	9.01
F	50	0.014	1.347	2.499	0.703	34.51	14.93	0.15	14.91	27.68	7.80
D	57	0.109	2.555	2.114	0.552	13.44	19.65	1.37	32.08	26.51	6.93
D	58	0.592	1.371	1.121	0.451	20.18	22.68	9.57	22.16	18.12	7.29
Total		25.510	68.688	48.887	37.391	587.21	807.99	211.97	850.12	761.90	380.74
No. of Mines		40	36	38	40	36	36	36	36	36	36
Average		0.638	1.908	1.286	0.935	16.31	22.45	5.89	23.61	21.16	10.58

TABLE 4 (CONCLUDED)

CHARACTERISTICS OF MIXED-POWER MINES USING STEAM AND GENERATED ELECTRIC POWER

Class	Number of Mine	Total Daily Cost For Hoisting—Dollars	Total Daily Cost For Ventilation—Dollars	Total Daily Cost For Pumping—Dollars	Total Daily Cost For Mining—Dollars	Total Daily Cost For Haulage—Dollars	Total Daily Cost For Miscellaneous—Dollars
C	1	1.17	1.89	45.45	19.16	5.41	13.92
A	4	33.74	43.72	1.86	......	......	7.28
C	5	16.89	32.09	0.82	65.48	32.64	10.05
A	6	35.40	40.14	5.26	......	......	5.80
B	7	7.58	30.72	1.58	......	12.72	2.35
C	8	5.26	18.38	12.19	19.84	4.93	9.00
D	11	172.28	47.30	9.94	15.94	13.04	80.85
B	12	88.70	102.82	88.44	9.54	7.82	82.34
D	13	41.58	100.51	9.55	57.25	33.43	21.68
C	14	10.87	63.49	5.72	57.90	17.49	17.48
C	15	13.64	20.13	1.91	46.35	8.09	11.38
D	16	17.27	40.30	3.56	50.82	13.42	12.13
D	18	22.67	42.98	1.47	42.66	13.55	6.67
D	19	40.73	34.26	4.87	97.47	40.63	31.52
C	20	89.48	129.03	0.82	106.45	87.00	38.88
B	21	7.72	3.35	48.86	......	54.42	21.65
C	24	13.42	19.12	18.74	8.77	29.89	12.06
F	26	34.13	47.55	0.95	26.68	54.40	7.99
D	28	12.43	40.73	0.52	23.35	40.73	14.24
C	29	64.38	160.80	0.75	89.52	73.17	24.69
C	30	21.36	40.05	0.33	78.90	74.88	16.65
F	31	187.80	129.99	25.10	91.47	74.73	54.12
F	32	22.56	47.37	0.66	18.99	45.57	9.36
D	33	37.03	66.11	0.16	87.04	28.00	8.16
D	34	13.18	58.46	30.56	27.65	37.09	17.38
D	35	81.37	82.60	163.98	43.50	35.56	62.37
C	39	35.40	42.88	11.80	83.56	109.72	55.64
C	40	15.68	30.92	0.32	23.12	36.04	10.92
D	41	54.68	83.96	1.48	104.65	59.04	23.52
D	42	45.47	47.60	2.15	116.55	16.35	37.88
G	43	78.48	67.56	0.76	51.80	130.16	65.24
C	44	30.08	30.83	0.46	45.05	89.61	22.13
C	45	37.25	33.81	12.22	65.77	58.38	44.57
D	46	42.50	79.34	8.06	40.66	95.26	12.02
C	47	39.82	23.76	0.13	70.22	100.81	26.39
C	48	33.07	34.72	0.43	42.81	90.30	36.66
C	49	34.91	30.93	0.44	42.57	89.66	19.65
F	50	161.90	70.04	0.70	69.95	29.86	36.59
D	57	35.32	51.65	3.60	84.32	69.68	18.23
D	58	74.88	84.18	35.53	82.27	67.26	27.06
Total		181.208	215.607	562.13	200.800	198.074	103.650
No. of Mines ..		40	40	40	36	38	40
Average		45.30	52.90	14.05	55.77	52.12	25.91

branches of operation. The results of the calculations were promptly accepted by these operators and the opinion was expressed that they were probably substantially accurate. At any rate the method received commendation for the enlightenment it affords, even if its results are not exact.

To illustrate the working of this scheme concretely, the following data for mine 14 are given. This mine has a hoisting depth of 154 feet and has an average production of 2200 tons per working day. Hoisting and ventilation are by steam power exclusively; main pumping is by steam and gathering pumping is by electricity; mining and haulage are both electric. The power units for the six activities were calculated as follows:

Hoisting (steam) $$\frac{2200 \times 2000 \times 154 \times 1.05}{33\ 000 \times 60 \times .85} = 423$$

Ventilation (steam) $$\frac{2.7 \times 5.2 \times 104\ 000 \times 24}{33\ 000 \times .50 \times .85} = 2519$$

Main pumping (steam) $$\frac{10\ 000 \times 8.3 \times 105 \times 1.05}{60 \times 33\ 000 \times .60 \times .85} = 91$$

Gathering pumping (electrical) 16.75 kw. for 5 hours daily (metered) $$\frac{16.75 \times 5 \times 1.34}{.82} = 137$$

Mining, breast machines $$\frac{6 \times 5 \times 9 \times 1.34}{.85 \times .85} = 501$$

Mining, short-wall machines $$\frac{13 \times 5 \times 14.9 \times 1.34}{.85 \times .85} = 1795$$

Haulage $$\frac{40 \times 2000 \times 352 \times 5}{9 \times 33\ 000 \times .85 \times .85 \times .95} = 695$$

Miscellaneous	Steam	Electric
Surface pumping	61	
Screens	170	
Shops		244
Illumination		135
Compressor	78	
Wash-house	6	
	315	379

Energy Units* Consumed

Activities	Steam	Electric	Per Cent of Total
Hoisting	423	....	6.17
Ventilation	2519	....	36.75
Pumping	91	137	3.33
Mining	....	2296	33.49
Haulage	....	695	10.14
Miscellaneous	315	379	10.12
	3348	3507	100.00

Total energy units 6855 steam horsepower-hours.

No electricity is purchased for this mine. The daily expense of generating power here is $172.95. Each of the 6855 power units therefore costs 2.523 cents. By using this figure it is now easy to calculate the daily costs and the costs per ton for each activity.

Similar reasoning will solve the power-cost-segregation problem at mines using steam only or electricity only. In the case of wholly electrified mines, the method applies when part or all of the electric power is obtained from outside sources. The calculation of all such cases will be simpler than for mixed-power mines.

In calculating the steam-generation cost figures presented in this publication, a fixed value of $2.40 per ton was assigned to the fuel consumed in the boiler house in every case. This was done in order to make the method of deriving these values uniform throughout, which is obviously necessary if the cost figures for the different mines are to have any value for the purpose of comparison. This value of $2.40 per ton is a purely arbitrarily assumed one which was, however, accepted by most operators with whom it was discussed, as being as fair an average value as could be ascertained. This expedient was adopted only after extensive efforts to use, for each mine, the actual values of the fuels used and at the same time to make the figures reasonably comparable. This was found to present insurmountable difficulties. It was equally impossible to devise a standard method of handling this item of cost which would be acceptable to all operators for use in their cost records. The uniform cost price of $2.40 per ton is used in this work, therefore, simply to reduce all the cost figures to a comparable basis.

*Steam horsepower-hours.

31. *Mixed-Power Mines Using Steam Power and Generated Electric Power.*—Table 4 gives a complete analysis of the distribution, cost, and consumption of steam and electricity in the mixed-power mines that use steam and generated electricity for power. Forty mines are listed but, of these, four use neither steam nor electricity for either mining or haulage, and are excluded from the estimates of average power distribution. These averages are, therefore, for 36 mines only or all of the mines listed in Table 4 with the exception of Mines 4, 6, 7, and 21.

The average daily production for the 40 mines is 3027 tons. The average hoisting depth is 402 feet. The arithmetic averages of the energy costs are 4.040 cents per ton for energy consumed as live steam and 4.328 cents per ton for energy consumed as electricity. This gives a total average cost of 8.368 cents per ton; the weighted average unit cost, however, is only 7.702 cents per ton. The cost for the six items hoisting, ventilation, pumping, mining, haulage, and miscellaneous, is divided as shown in Table 5.

In this table the unit cost for ventilation is higher than the unit cost for mining, but the total daily cost for mining is slightly higher than the total daily cost for ventilation. This is accounted for by the fact that the average and the total for mining are for only 36 mines while the average and the total for ventilation are for 40 mines. Mines 4, 6, 7, and 21 use manual labor for mining. Mines 4, 6, and 7 have excessive power consumptions for ventilation, viz., 60.48 per cent, 46.35 per cent, and 53.91 per cent of their total power, respectively.

The four items, hoisting, ventilation, haulage, and mining, are the chief sources of expense, their total consumption averaging 83.53 per cent of the total energy consumption. In a few cases very large amounts of energy are consumed by pumping. Energy required for pumping depends upon the wetness of a mine and is not a function of the tonnage, height of hoisting, or any other regular item in mining.

A summation shows the following average energy distribution:

Hoisting	16.31 per cent
Ventilation	22.45 per cent
Pumping	5.89 per cent
Mining	23.61 per cent
Haulage	21.16 per cent
Miscellaneous	10.58 per cent
	100.00 per cent

TABLE 5

AVERAGE DISTRIBUTION OF TOTAL ENERGY COST TO SIX MAJOR ACTIVITIES

	Hoisting	Ventilation	Pumping	Mining	Hauling	Misc.
Cost in cents per ton........	1.562	1.970	0.683	1.889	1.254	0.926
Total daily cost in dollars....	43.31	53.04	14.04	54.82	50.44	25.46
Number of mines...........	40	40	40	36	38	40

These results for 40 mines agree closely with the averages given in Table 2 for 50 mines. Mines 1, 8, 12, 34, and 35 have excessive consumptions for pumping. Omitting these, the averages for mines having normal pumping requirements are:

Hoisting..........................	17.12 per cent
Ventilation.......................	22.69 per cent
Pumping..........................	2.14 per cent
Mining...........................	24.93 per cent
Haulage..........................	23.19 per cent
Miscellaneous.....................	9.93 per cent
	100.00 per cent

All the items are increased somewhat except pumping, which is decreased 3.75 per cent, and Miscellaneous, which is decreased 0.65 per cent.

TABLE 6

RELATION OF ENERGY DISTRIBUTION TO TONNAGE

DAILY PRODUCTION TONS	PERCENTAGE OF TOTAL ENERGY CONSUMED						
	No. of Mines	Hoisting	Ventilation	Pumping	Mining	Haulage	Misc.
1000-Less....................	1	1.35	2.17	52.24	22.01	6.22	16.01
Above 1000 up to and incl. 2000..	4	23.10	21.93	11.06	19.30	8.41	16.20
Above 2000 up to and incl. 3000..	14	15.56	27.76	2.80	25.71	19.51	8.66
Above 3000 up to and incl. 4000..	9	14.67	21.99	6.46	25.34	20.76	10.77
Above 4000 up to and incl. 5000..	6	14.84	15.66	1.40	20.96	36.03	11.11
Above 5000 up to and incl. 6000..	2	27.35	18.81	4.86	18.54	22.90	7.54
Average—3026.7...............	36	16.31	22.45	5.89	23.61	21.16	10.58

TABLE 7
RELATION OF HOISTING DEPTH TO POWER DISTRIBUTION

Depth Feet	No. of Mines	Per cent of Total Energy					
		Hoisting	Ventilation	Pumping	Mining	Haulage	Misc.
100–200	4	5.57	24.52	24.42	24.75	10.89	12.12
200–300	5	15.93	19.10	12.44	26.10	13.23	13.20
300–400	11	14.24	21.52	2.39	22.73	28.74	10.38
400–500	7	14.76	22.85	1.29	33.49	18.57	9.04
500–600	4	16.71	30.52	4.14	17.91	24.15	6.57
600–700	5	31.68	19.36	1.66	12.91	21.90	12.49
Average 401.7	26	16.31	22.45	5.89	23.61	21.16	10.58

Table 6 shows for the 40 mines covered by Table 4 the relationship of the energy distribution to the daily production. There is only one mine having a daily production of less than 1000 tons, and this is not a truly representative mine because of the excessive consumption of energy in pumping.

Mines producing from 1000 to 2000 tons daily use 23.10 per cent of their power for hoisting and mines producing between 5000 and 6000 tons daily consume 27.35 per cent; but the remaining mines (those between 2000 and 5000 tons daily production) average about 15 per cent for hoisting.

The energy consumed in ventilation has a tendency gradually to decline as the production increases, as also that consumed in pumping and mining. The energy consumed in haulage logically increases as the production increases. Exceptions to this general statement are explainable, in one instance by the exclusive use of mules for gathering, but more generally by better track conditions in the larger mines.

The miscellaneous percentages remain nearly constant, the larger percentages being found among those mines that have the smaller daily productions.

Table 7 shows the relationship between the power distribution and the hoisting depth. Depth of seam has little or no definite relation to cost of ventilation, mining, haulage, and miscellaneous items, although it is a real factor in hoisting and pumping costs. As the hoisting depth increases, the percentage of power used in hoisting naturally increases. On the other hand, the percentage of power used for pumping generally decreases because deep mines are usually drier than shallow mines.

TABLE 8
CHARACTERISTICS OF MIXED-POWER MINES USING STEAM AND PURCHASED ELECTRIC POWER

Mine Number	9	22	25	36	37	38	Total	Number of Mines	Average Per Mine
Class	E	G	C	G	G	G			
Daily Production, tons	1750	2635	2700	3500	3710	3770	18065	6	3011
Hoisting Depth, feet	259	463	284	309	421	404	2140	6	357
Cost of Fuel, per day at $2.40per ton, dollars	28.80	6.00	100.80	....	....	....	....	....	....
Cost of Boiler-Room Labor, per day, dollars	7.70	....	36.00	....	....	10.00	....	....	....
Boiler-Room Maintenance Overhead Cost, per day, dollars	4.75	....	10.00	....	....	....	....	....	....
Total Daily Power Cost, dollars	61.41	116.00	219.08	285.40	243.00	194.80	1119.69	6	186.61
Steam Hoisting, per day, st. h.p.-hr. at 85% efficiency	459	....	792	....	....	....	1251	2	625
Electric Hoisting, per day, st. h.p.-hr. at 85% efficiency	....	2943	....	3377	3925	3925	14170	4	3542
Fan Engine, per day, st. h.p.-hr. at 81% efficiency	....	....	1140	....	....	....	1140	1	1140
Fan Motor, per day, st. h.p.-hr. at 85% efficiency	736	1962	....	3263	3434	3107	12502	5	2500
Steam Pumping, per day, st. h.p.-hr. at 49% efficiency	....	....	134	....	....	....	134	1	134
Electric Pumping, per day, st. h.p.-hr. at 51% efficiency	156	196	27	....	981	164	1524	5	305
Mining, per day, st. h.p.-hr	....	2617	1511	2576	4906	4906	16516	5	3303
Haulage, per day, st. h.p.-hr	814	916	1008	9044	1913	2944	16639	6	2773
Miscellaneous, as steam, per day, st. h.p.-hr	100	30	1013	....	....	50	1193	4	298
Miscellaneous, as electricity, per day, st. h.p.-hr	66	330	436	2632	1164	931	5559	6	926
Total, st. h.p.-hr. per day, as steam	559	30	3079	....	....	50	3718	4	929
Total, st. h. p.-hr. per day, as electricity	1772	8964	2982	20892	16323	15977	66910	6	11151
Total Daily Power Consumption, st. h.p.-hr	2331	8994	6061	20892	16323	16027	70628	6	11771

TABLE 8 (CONCLUDED)
CHARACTERISTICS OF MIXED-POWER MINES USING STEAM AND PURCHASED ELECTRIC POWER

Mine Number	9	22	25	36	37	38	Number of Mines	Weighted Average
Class	E	G	C	G	G	G		
Cost in cents per st. h.p.-hr.	2.63449	1.28974	3.61458	1.36607	1.48869	1.21545	6	1.58533
Cost of Steam, per day, used as live steam, dollars	41.25	6.00	146.80	....	....	10.00	4	34.01
Cost of Steam, in cents per ton	2.356	0.227	5.437	....	....	0.265	4	1.12953
Cost of Electricity, per day, dollars	20.16	110.00	72.28	285.40	243.00	184.80	6	152.61
Cost of Electricity, in cents per ton	1.153	4.175	2.677	8.154	6.550	4.902	6	5.06858
Total Daily Power Cost, in cents per ton	3.509	4.402	8.114	8.154	6.550	5.167	6	6.19811
Cost, in cents per ton, of power for:								
Hoisting	0.691	1.440	1.060	1.318	1.575	1.265	6	1.353
Ventilation	1.108	0.961	1.526	1.274	1.378	1.002	6	1.197
Pumping	0.235	0.096	0.216	....	0.393	0.053	6	0.146
Mining	....	1.280	2.023	1.005	1.969	1.582	6	1.449
Haulage	1.225	0.448	1.349	3.530	0.768	0.949	6	1.460
Miscellaneous	0.250	0.177	1.940	1.027	0.467	0.316	6	0.593
Distribution of Power, per cent:								
Hoisting	19.69	32.71	13.06	16.16	24.05	24.48	6	21.83
Ventilation	31.58	21.81	18.18	15.62	21.04	19.39	6	19.32
Pumping	6.70	2.18	2.66	....	6.00	1.03	6	2.35
Mining	....	29.10	24.93	12.33	30.04	30.61	6	23.38
Haulage	34.91	10.18	16.64	43.29	11.73	18.37	6	23.56
Miscellaneous	7.12	4.02	23.90	12.60	7.14	6.12	6	9.56
Total Daily Power Cost, in dollars, for:								
Hoisting	12.09	37.94	28.62	46.13	58.45	47.69	6	40.75
Ventilation	19.39	25.32	41.20	44.59	51.13	37.78	6	36.04
Pumping	4.11	2.53	5.83	....	14.59	2.00	6	4.38
Mining	....	33.75	54.63	35.18	72.99	59.64	6	43.64
Haulage	21.45	11.80	36.42	123.55	28.50	35.78	6	43.96
Miscellaneous	4.38	4.66	52.38	35.95	17.34	11.91	6	17.84

32. *Mixed-Power Mines Using Steam and Purchased Electric Power.*—Owing to the incomplete data on this type of mine, there are only six such mines listed in Table 8. These six mines are truly representative mines and the results are reliable. This table is a complete analysis of the distribution, cost, and consumption of the power in mixed-power mines that use steam and purchased electricity. Mine 9 uses steam for hoisting and miscellaneous, and purchased electricity for all other uses. Mine 25 uses steam for hoisting, ventilation, main pumping, and miscellaneous. The remaining four use purchased electricity for all purposes and steam for heating water for the wash-houses.

Table 9 lists the chief items of Tables 4 and 8 and shows the comparison of the characteristics of these two types of mines, i.e., of mixed-power mines that use generated and purchased electric energy respectively.

The average daily production for the mines using generated power is 3027 tons, and for the mines using purchased power it is 3011 tons. The average hoisting depth in the first case is 402 feet, and in the latter case it is 357 feet.

The total daily power cost for the mines using generated power is \$238.89 and that for the mines using purchased is only \$186.61, or 21.89 per cent less. The cost in cents per ton for steam is 3.088 in the first case and 1.129 in the latter case. This wide difference is due to the fact that four of the six mines using purchased power use steam for no other purpose than heating water for the wash-houses. The cost in cents per ton for purchased electric energy is logically higher (generated 4.805, purchased 5.069) because it is used for more purposes. The real test is a comparison of the average total daily power costs in cents per ton between the two types of mines. The generated-power mines have an average total daily energy cost of 7.893 cents per ton, while the purchased-power mines have an average cost of only 6.198 cents per ton, a difference of 1.695 cents per ton, or 21.47 per cent.

A study of the unit costs in cents per ton for the six items, hoisting, ventilation, pumping, mining, haulage, and miscellaneous, shows that the average cost in purchased-power mines is smaller for every activity except hoisting.

The percentage of energy consumed for hoisting and mining is larger in the purchased-power mines than in the generated-power mines.

TABLE 9
RÉSUMÉ OF GENERATED-POWER AND PURCHASED-POWER CONSUMPTION FIGURES

Item	Generated	Purchased
Average daily production	3027	3011
Average hoisting depth	402	357
Average total daily power cost, dollars	238.89	186.61
Average cost of steam as live steam, cents per ton	3.088	1.129
Average cost of electricity, cents per ton	4.805	5.069
Average total daily power cost, cents per ton	7.893	6.198
Average cost in cents per ton for hoisting	1.253	1.353
Average cost in cents per ton for ventilation	1.710	1.197
Average cost in cents per ton for pumping	0.453	0.146
Average cost in cents per ton for mining	1.721	1.449
Average cost in cents per ton for haulage	1.941	1.460
Average cost in cents per ton for miscellaneous	0.815	0.593
Average per cent power distribution, hoisting	15.88	21.83
Average per cent power distribution, ventilation	21.66	19.32
Average per cent power distribution, pumping	5.74	2.35
Average per cent power distribution, mining	21.81	23.38
Average per cent power distribution, haulage	24.59	23.56
Average per cent power distribution, miscellaneous	10.32	9.56
Average total daily power cost in dollars, hoisting	37.94	40.75
Average total daily power cost in dollars, ventilation	51.75	36.04
Average total daily power cost in dollars, pumping	13.70	4.38
Average total daily power cost in dollars, mining	52.10	43.64
Average total daily power cost in dollars, haulage	58.74	43.96
Average total daily power cost in dollars, miscellaneous	24.66	17.84

IX. COMPARISON OF ESTIMATED WITH METERED POWER CONSUMPTION FIGURES

33. *Metered and Estimated Figures for Different Mines.*—Comparison of some of the power-consumption estimates, derived in the manner described in the preceding chapter, with figures secured by actual metering of the power consumed in similar operations at other mines indicates the probable average reliability of these estimates and shows as well how the practice of distributed power-cost accounting, by keeping the management informed, may lead to more economical and efficient power utilization.

While the general method described for estimating the power consumptions at mixed-power mines was applied throughout, great differences in the accuracy and completeness of fundamental data available at the different mines necessitated treating each mine more or less individually in arriving at these estimates. All the information securable was used to make the estimates as accurate as possible. At many mixed-power mines accurate data on some of the factors which enter into these estimates were available and were used. It was gratifying to note how closely the average figures for the two groups check on most items, showing the reasonableness and general reliability of the estimated figures.

Power consumption is metered at eight mines (9, 22, 25, 36, 37, 38, 39, and 50) most of which purchase their power. The group for which the power-consumption figures are mainly estimates comprises 33 mines. Only those mines at which all the major activities are performed mechanically were considered. Classes A, B, and E, where either mining or haulage is performed by manual or animal power were omitted, as obviously such mines are not comparable, as regards either total power consumption or percentage distribution of power consumption to the major functions, with the completely power-operated mines. Complete power distribution data for the individual mines in these two groups may be found in Tables 4 and 8. With respect to depth of shafts and to size of mines as indicated by daily tonnage—the two principal conditions which might be expected to affect the relative power consumptions—the two groups compare closely; the eight metered-power mines averaging 3408 tons in daily production and 396 ft. in depth, and the 33 estimated-power mines averaging 3136 tons production and 404 ft. in depth. On this score, therefore, the comparableness of the power consumption figures need not be questioned.

The total power consumption at the eight mines which meter their power averages 3.51 steam horsepower-hours per ton of coal produced as against 3.66 steam horsepower-hours per ton at the 33 estimated-power mines. The percentage distribution of power to the six major divisions in the metered-power mines and in the estimated-power mines, respectively, is as follows: hoisting, 21.90 and 16.27; ventilation, 14.40 and 22.80; pumping, 2.77 and 5.61; mining, 23.75 and 24.18; haulage, 24.40 and 20.99; miscellaneous, 10.64 and 10.14. Power-cost figures for the two groups do not agree so closely. The average total power-cost per ton of coal produced is 6.674 cents at the metered-power mines and 8.31 cents at the estimated-power mines. The close check between the two groups in power units consumed per ton indicates that the source of this difference in the power-cost figures is in power production rather than in its utilization. Those who advocate the use of purchased power may interpret these figures as showing a lower cost per unit of power at the purchased-power mines, which make up a large part of the group of mines at which the total power used is metered. There are, however, other factors which no doubt exert an influence toward more efficient production and utilization of power at mines of this group. It is to be expected that those operators who meter the power consumed in the various activities and concern themselves with power distribution and power consumption records will introduce economies which ultimately result in lower power costs.

This is the case in the 58 mines selected for study. It was observed in all the tabulations in which the mines were arranged in ascending order of unit costs, that those mines which were able to furnish the most complete itemized data on power distribution were grouped generally in the first half of the table showing relatively low total power costs. This condition could hardly be ascribed to inaccuracies in the figures for the mines which submitted meagre data, because fairly accurate total power production costs were procurable at practically all of the mines.

34. *Comparison of Metered and Estimated Power Consumption Figures for the Same Mines.*—As a further check on the methods used in estimating power consumption, the figures which were obtained by actual metering, both at the electrified mines and at the mixed-power mines, were duplicated by estimating the same power consumptions from the fundamental data. Comparison of the two sets of figures led to modification and adjustment of the factors used in the method of estimation by which the final figures presented in this bulletin were secured. In this way the recorded data secured at mines where power readings have been taken were very helpful in estimating similar power consumption figures at other mines where no such data were available, and the estimates were by this means made more accurately.

Mining and haulage power consumptions were the most difficult items to calculate because of irregularity of operation and consequent difficulty in determining the actual operating time, particularly of the mining machines. When the power consumptions were calculated, therefore, on the basis of full-load power consumption by each machine, average number of hours operated per day, and the percentage efficiencies of the various power transforming and transmission units between the point of consumption and the point of generation of the power, it was found that the estimated figures usually exceeded the metered figures by a considerable amount. This is ascribed to overestimation of the net operating time during which the machine is actually using power. Fortunately, enough actual metered data were available to evaluate these factors satisfactorily.

In the case of two of the items, ventilation and pumping, it was found that, in the majority of cases, calculations of the work required to move the air or the water, taking into consideration the accepted efficiency ratings of the various machines and transmission units involved, checked fairly well with the meter readings, although there were, of course, exceptions.

As regards the power consumed in hoisting, calculation of the work done in lifting the coal produced through the distance hoisted plus the power losses ordinarily allowed for the hoisting engine or motor, and for the transmission line, gave figures in each case considerably lower than actual meter readings. This was ascribed to the necessarily inefficient use of power in the hoisting operation due to rapid acceleration followed by braking.

Of the group of mines selected for study only four use electric hoists and, therefore, only four sets of actually metered figures on hoisting power are available. It is noteworthy, however, that for three of these four mines, which happen to be of nearly the same hoisting depth, the factor by which the theoretical power consumption must be increased in order to make it equal to the actual power consumption is practically a constant. At mine 22, which has a hoisting depth of 456 ft., this factor is 1.58; at mine 37, hoisting depth 421 ft., it is 1.65; and at mine 38, hoisting depth 404 ft., it is 1.66. At the fourth mine, 36, which has a much shorter hoisting distance (309 ft.) this factor is much larger, namely, 1.97. Although these data are meagre they may be interpreted as indicating that this factor is quite uniformly dependent upon hoisting depth, and they check without exception the commonly accepted idea that the short hoist, made up entirely of the accelerating and the braking periods, is most inefficient in the use of power. It will be observed that, in the case of these four mines, the efficiency varies directly with the hoisting depth, that is, the factor referred to above increases with decreasing hoisting depth.

X. Public-Utility Power at Illinois Mines

35. *Public-Utility Power Generation in Illinois.*—The United States Geological Survey issues monthly reports, entitled "Production of Electric Power and Consumption of Fuel by Public-Utility Power Plants in the United States." Table 10 is extracted from such reports for the months of April, May, June, July, and August, 1923, and is presented to show that the State of Illinois ranks third in the amount of

TABLE 10
COAL CONSUMED BY PUBLIC-UTILITY COMPANIES IN LEADING STATES

State	Average Tons per Month	Average Kw-hr. per Month	Average lb. Coal per Kw-hr.
New York	392 769	400 727 000	1.99
Pennsylvania	455 493	394 342 000	2.31
Illinois	397 303	307 203 000	2.59

electric power produced by the burning of coal. New York stands at the head in regard to the amount of power generated, while Pennsylvania leads in the amount of coal consumed.

During this same five-months period, of the total of 4 568 947 000 kw-hr. of electric power generated monthly in the United States, the average generation of electric power per month from the combustion of fuels was 2 825 668 000 kw-hr., while the energy generated by water power averaged 1 743 279 000 kw-hr. The term fuels in these statistics includes coal, wood, natural gas, and oil. In the principal coal-producing states, especially in Illinois, the consumption of natural gas, wood, and oil was negligible.

In Illinois, during this same period, public-utility companies generated from water power and distributed an average of 16 254 000 kw-hr. per month.

These figures show that Illinois produced 10.87 per cent of all the electric power produced in the United States through the use of fuels and that this was done practically from coal only. This indicates that public-utility power generation in itself furnishes a strong market for the products of the Illinois coal-mining industry.

Another interesting deduction from these figures is that, of the entire quantity of electric power generated throughout the United States, 62 per cent is produced through the use of fuels.

A third interesting item for consideration in these statistics is the economy that is attained in up-to-date power plants in the production of electricity through the burning of coal. In New York state one kilowatt-hour of electrical energy was produced per 1.99 pounds of coal burned under boilers. The efficiency in Illinois was not as good as this and yet its figure of 2.59 pounds of coal per kilowatt-hour is a noteworthy achievement. With coal costing $3 per ton or 0.15 cents per pound, these figures mean that in our best American practice the fuel cost of a kilowatt-hour of electricity is only 0.30 cents to 0.39 cents.

This high efficiency in modern practice is attained through the use of the very best types of boilers and condensing steam turbines working on a large scale. In order to get the highest efficiency from turbines there must be first-class condensing conditions and usually this requires an abundance of water. Power companies in many cases have gone to great expense to provide themselves with sufficient condensing water. One large generating plant is being built on the banks of the Mississippi River, simply to obtain a cheap and adequate supply of water.

36. *Advantages of Purchased Power for Mining Companies.*—The purchase of central-station power for coal-mine operations began in Illinois about 1910. Electric hoisting, depending upon purchased power, was first practised in the state in 1913. At present more than one-fourth of the mines in the state are operated partly or wholly by such power. Their daily productions range from a few hundred tons up to several thousand tons, thus indicating that purchased power is not peculiarly or exclusively adapted to operations upon any particular scale. One power company claims to be supplying all or part of the power requirements of 50 mines in Illinois, the maximum demand at any one mine being 2200 kw.

These public-utility companies make strong bids for coal-mining business despite their own assertions that the requirements of mining entail unusually bad load conditions. Arguments advanced by officials of power companies in favor of the purchase of electric power by mining companies invite discussion.

When opening a new mine, the exclusive use of purchased electric power will obviate a heavy investment for power-generating apparatus. In the replacement of steam by electricity for any purpose around an old mine, the same argument applies. However, interruptions in electric-power generation and transmission do occur from unavoidable causes. Therefore the argument is not strictly valid, for a mine must be provided with its own power-generating equipment to at least maintain ventilation and man-hoisting during such emergencies.

The flexibility in power supply that takes care of quick increases in power demand when enlarging mine productions is a good argument for the purchase of electricity. Instead of adding more boilers and engines, an operator desiring to increase his output need only install additional transforming apparatus. This is all very well if the power company be prepared to promptly and effectively supply this new demand. Power companies sometimes sign contracts to furnish power in excess of their capacity.

The lack of adequate water supply for boiler feed may be of such significance as to warrant an operator in purchasing his power as electricity.

During labor disturbances—such as the strike of 1922—it has been possible for some Illinois mines to avoid flooding and to maintain ventilation by the use of central-station power, without which serious loss might have resulted. Certain operators who had previously opposed the adoption of purchased power were glad to receive this power in the emergency.

A mine operating with purchased power for all activities need not close down at any time for repairs to generating equipment. This point advanced in favor of public-utility power implies either that the equipment of the central power plant never requires repair or that it is sufficiently duplicated to maintain full contracted power demands during periods of repair.

The chief argument for purchased-power practice is a lowering of mining costs per ton. Statistics issued by officials of power-vending companies indicate that substantial economies have been effected by coal operators in the adoption of purchased power. The claim is made that savings of from 5 to 10 cents per ton have thus been made in power costs at large, fully electrified mines, and that a saving of from 2 to 5 cents per ton will result from replacing the best existing types of individual power plant with central-station service. This argument of economy is seriously questioned, not so much with regard to the relative economic positions of locally generated and of purchased power, but more particularly regarding the figures just cited. Many mines are operating at a power cost of around 10 cents per ton and they are generating their own power.

This is one of the most actively discussed questions in regard to mine power costs. There is no doubt that many small mines or short-lived mines, at which the installation of a highly efficient power plant is not justified, could be more economically operated on purchased power than on generated power. Many hold it to be equally obvious that a mining company, with a dependable fuel supply at its own pit-mouth and a use for its power production in its own plant (thus avoiding the transportation of fuel and the maintenance of and power losses in transmission lines) can generate power more cheaply than it can purchase it—provided the scale of operations, and consequently the power requirement, be sufficient to warrant generation on a scale that makes highly efficient equipment and operation possible. The minimum scope of operation at which this condition may exist will vary in different cases, but 3000 tons per day production is a figure often given by advocates of the local power generation plan as the natural dividing line under normal conditions. It is argued that mines producing over 3000 tons of coal per day and with sufficient acreage of coal available to insure operation long enough to amortize an adequate power-plant investment at a reasonable rate, can probably generate power in an efficient plant more economically than they can purchase it from a utility company which is dependent upon the same fuel supply.

The experience of those who have installed low-pressure turbines shows that there would be a large saving at the mixed-power mines if the exhaust steam from the hoisting engines were utilized in mixed-pressure turbines to generate electrical power that would replace purchased power. On the other hand, several operators of large mines with well-equipped power plants have found that even under these conditions they cannot generate power as cheaply as they can purchase it. One noteworthy example is furnished by the experience of a large corporation operating a 5000 kv-a. central power plant for a group of mines. Even with this well-equipped plant the cost of power generation exceeds the rate offered by the utility company which operates in that district, and operation of the mine power plant has been discontinued except in cases of emergency. The principal source of difficulty at this particular plant is insufficient water supply, a common difficulty in mine power-plant operation in the southern Illinois field.

Actual power-cost figures, secured in the course of this investigation, substantiate the claim made by power companies that many mine operators—perhaps most mine operators—could save money by purchasing their power. Their estimates of the magnitude of the saving as quoted above, however, are not borne out. While the purchased-power mines are grouped together among the lowest cost mines of the state, and their average unit power cost is much lower than that of the generated-power mines, there are several mines which generate their own power at equally low cost. The average cost of power at the eight mines which purchase all their electrical power is 1.795 cents per steam horsepower-hour, as against an average of 2.215 cents at the generated-power mines and 1.657 cents at the lowest 25 per cent of the generated-power mines. To secure these figures all in the same units, purchased power in kilowatts has been calculated by the usual conversion factor to horsepower. To become available for underground use, both forms of power ordinarily have to be converted into low voltage direct current

FIG. 2. POWER TRANSMISSION-LINE MAP OF ILLINOIS

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by practically equivalent processes—in the case of the generated-power mines by engine-generator sets; at the purchased-power mines by transformers and motor-generator sets.

Public-utility power service has grown steadily in magnitude. It is a large industry in itself and it has had many obstacles to overcome in its relatively rapid evolution. There have been many instances of disappointed power consumers and likewise of disheartened power producers. Despite the fact that power-vending companies have often undertaken service beyond their capacities, no one should doubt the serious presumption of the officials that their equipment was adequate to meet the demands. The success of their business depends upon satisfied customers and it is logical to assume that every effort is being made by these companies to deliver efficient service. They continually invest large sums in betterments in and additions to generation and transmission equipment, confident that future business will justify these efforts and expenditures.

A transmission-line map of Illinois, Fig. 2, bears some resemblance to a railroad map. Until one examines such a map he probably fails to realize how extensive this public-utility power business has become in such a brief time. Central-station companies desire customers in all power-consuming trades and they must give universal satisfaction in their service. In certain parts of the state, coal mining is the predominant or only industry. It is interesting to note that power companies are making special advances in these areas.

There are, in Illinois, approximately 6500 miles of electric-power transmission lines owned by public-utility corporations. Although these lines belong to many competing companies, they are being intimately inter-connected so that there can be a reliable exchange of service in times of emergency and heavy loads. There is a uniform practice of transmitting power at a voltage of 33 000, higher pressure being deemed inadvisable because of the closely populated condition of the state, and unnecessary because of the relatively short distances that current must be transmitted. The current is 3-phase and 60-cycle.

XI. Public-Utility Rates

37. *Complexity of Rate Schedules.*—The power-vending companies operating in Illinois have rate schedules that, to the average consumer, appear needlessly complex. Further, the various power companies do not follow similar schedules. Even if a superintendent were positive

that his mine would be operated a specified number of days per month and that his actual consumption of power would average a certain number of kilowatt-hours per day, he would still be at a loss to estimate approximately his power bill in advance when guided only by a power schedule. If he has had previous experience, or if he can secure power-cost data for other mines operating with equipment and under conditions somewhat similar to his, he may roughly guess regarding his monthly power bill. Some coal operators have worked for such extended periods with purchased power that they have deduced averages of their energy consumption and of energy costs per ton of coal produced—very infrequently, however, for each principal branch of the mining work.

Each power company formulates its schedules of charges according to its own notions of equity and profits. Such schedules are similar only in one general feature that they contain two classes of charges; but even these classes are given different names by different companies and are calculated in unlike ways. The first class of these charges for purchased electric power is variously termed the primary, demand, or active-load rate. The second class of charges is termed the secondary or energy rate.

38. *Secondary Charges.*—This charge is based upon the amount of power actually consumed. A few schedules name fixed prices per kilowatt-hour regardless of the amount of energy consumed, but usually there is a sliding scale, with specific charges for certain numbers of kilowatt-hours, the rate decreasing as the consumption increases up to specified maximum amounts above which the charge is constant per kilowatt-hour. For a mine consuming 100 000 kw-hr. per month, the secondary charge may vary from 1.25 cents to 2.05 cents according to different schedules.

39. *Primary Charges.*—The primary, demand, or active-load charge, on the other hand, is a readiness-to-serve rate and while it is based nominally upon a customer's maximum possibilities of power consumption or upon his highest demands during a month, it really provides an income to cover the power company's investment overhead. For a monthly consumption of 100 000 kw-hr. the primary charge will generally be somewhat over one-third of the total bill.

A power company calculates the primary charge upon the basis that all of the consumer's connected electric apparatus may be operated simultaneously up to a certain percentage of full capacity. Since occasions of this sort never or seldom occur, it may seem unjust to maintain such a charge but, on the other hand, the customer has a perfect right under his contract to operate all his machines at one time. The power company must therefore stand prepared, often at heavy investment cost, to supply this unusual demand for current. Ordinarily all the electrical machines around mines do not run steadily or simultaneously so that the normal demand for power is considerably less than is indicated by the primary charges.

Sometimes the primary charge is based upon what is termed active load. By active load is meant a part of the total connected load, but instead of being a fixed percentage regardless of the extent of the full connected load, it is scaled to decrease as the horsepower of the connected load increases. This process again depends upon the number of motors comprising the load. For usual mining conditions the active load is approximately 50 per cent of the full connected load.

During a working shift there may occur brief abnormal load demands owing to concurrent heavy demands for hoisting, haulage, coal cutting, and pumping, in addition to the normal demands for ventilation, illumination, screening, and the usual surface activities. These short periods are known as "peaks" for they appear as summits in the load diagrams. When peaks are momentary they do not enter into the monthly rating. The power companies take no account of peaks lasting less than five minutes because their generating apparatus will sustain no injury in meeting such temporary excessive loads. To meet sustained heavy loads, of the same amount, however, the power-plant equipment must needs be of greater capacity. This is such a strong argument for the primary charge that some power companies prefer to base this charge upon five-minute peak loads rather than upon full connected loads.

A power company leaves it optional with a purchaser to contract upon either of two bases in determining the primary charge from peak loads—the monthly maximum demand or the annual maximum demand. By the monthly maximum demand is meant the average of the highest three five-minute peak demands occurring in the specified month. Such an average varies considerably from month to month. The annual maximum demand is the highest monthly maximum demand during the preceding year. Operating under the monthly maximum demand contract, the customer's bill is calculated from his peaks during the current month; whereas, operating under the annual maximum demand contract, he and the power company are bound by the highest monthly maximum demand shown in his operations during the preceding twelve months. The latter form of contract of one power company reads that its demand or primary charge during the first twelve months of service to a new customer shall be based upon the highest monthly demand occurring up to the month of billing.

Primary charges vary widely with different companies and are not easily compared. In general, they run from \$1.50 to \$2.50 per month for each kilowatt of maximum demand. Sometimes it is a flat rate regardless of scale of operations, and in other cases it is a sliding rate.

Nearly all electric-service contracts in Illinois provide for a prompt-payment discount of ten per cent from the secondary charge only.

40. *Examples of Purchased-Power Costs.*—As already stated, the most satisfactory manner of arriving at a fair conception of these rates and costs is to study power bills that have been rendered to mining companies.

One completely electrified mine that, during 1921, maintained an average working-day production of 3780 tons, had an average monthly power bill of \$3426, made up of a primary charge of \$1506 and a secondary charge of \$1920. This was at the rate of 5.04 cents per ton of coal. The actual amount of power consumed per month averaged 158 458 kw-hr., so that its cost per kilowatt-hour was 2.16 cents.

Another completely electrified mine with an average working-day production of 2630 tons consumed approximately 2.31 kw-hr. per ton of coal. This current also cost at the rate of 2.16 cents per kw-hr., thus making the power cost per ton of coal 4.98 cents. The annual bill for power was \$29 222.

Still another wholly electrified mine—one that had an average production of more than 2900 tons per working day throughout a year—had an average energy consumption of 3.65 kw-hr. per ton. The average cost per kw-hr. was 2.59 cents so that the power cost per ton of coal produced was 9.45 cents.

One mine with an average working-day production of 1500 tons, using purchased power for mining, main haulage, and main pumping only, had a monthly bill of \$1038, this being at the rate of 4.62 cents per kilowatt-hour or 3.46 cents per ton.

The first two of the cases quoted are believed to represent the highest economy for coal-mining power thus far attained in Illinois. The last case is representative of partly electrified mines using utility power. However, these figures must not be accepted as standing fully for purchased power costs because they do not cover such inevitable stand-by

TABLE 11

PUBLIC-UTILITY RATES

The first line in each group of schedules is the primary charge; the second line is the secondary charge; the third line is the total charge for month in dollars; the fourth line is the cost in cents per kw-hr. The kilowatts on which the primary charge is based are assumed at 0.5 per cent of the secondary charge in kilowatt-hours. This relation existed in a large number of actual monthly settlement sheets examined. A discount of 10 per cent is taken from the secondary charges.

	SCHEDULES							
Monthly Consumption kw-hr.	I	II	III	IV	V	VI	Primary Demand Average Per cent of Total	Average Cents per kw-hr.
	14	8	12	11	12	15		
	14	41	54	13	48	39	29.69	4.68
1 000	28	49	66	24	60	54		
	2.80	4.90	6.60	2.38	6.00	5.40		
	81	75	120	113	120	90		
	138	268	256	125	230	226	33.50	3.07
10 000	219	343	376	238	350	316		
	2.19	3.43	3.76	2.38	3.50	3.16		
	351	375	578	563	578	390		
50 000	688	988	778	625	842	1036	36.56	2.60
	1039	1363	1356	1188	1420	1426		
	2.07	2.72	2.71	2.38	2.84	2.85		
	689	750	1065	1125	1065	765		
	1375	1744	1363	1250	1607	2048	36.95	2.47
100 000	2064	2494	2428	2375	2672	2813		
	2.06	2.49	2.43	2.38	2.67	2.81		
	1701	1845	2528	2813	2528	1890		
	3438	3634	3128	3125	3902	5086	37.53	2.37
250 000	5139	5509	5656	5938	6430	6976		
	2.06	2.20	2.26	2.38	2.57	2.79		
	3389	3750	4965	5625	4965	3765		
	6875	6784	6043	6250	7727	10148	38.04	2.34
500 000	10264	10534	11008	11875	12692	13913		
	2.05	2.11	2.20	2.38	2.54	2.78		

expenses as interest on investment in special electrical equipment and the labor and materials for maintenance and repairs.

41. *Typical Schedules.*—Table 11 presents costs per month for public-utility power according to six different schedules in force for Illinois mine service and for six different volumes of power consumption. A study of many actual power bills shows that the amounts of the primary demands in kilowatts average 0.52 per cent of the secondary demands in kilowatt-hours. For simplicity in calculations this factor is

taken as 0.5 per cent. In other words, for mines consuming an average of 100 000 kw-hr. per month, the equipment could demand 500 kw. It should be borne in mind that this factor stands for average rather than best conditions. The estimated costs in the table are a trifle higher than the costs that prevail in best practice in which peak loads are systematically held low but they are lower than many instances of indifferent practice.

The charge for primary demand varies from 30 to 38 per cent of the total monthly bills, and instead of lessening with increasing power consumption, as might be supposed, this percentage actually does the reverse. This is due simply to the fact already explained that the seconday charge per unit (kw.-hr.) decreases as monthly consumption increases.

The costs of purchased power will vary from 4.68 cents per kilowatt-hour for the average small mine to one-half of this or 2.34 cents per kilowatt-hour for the average large mine. A fact not brought out by the table is that the cost per kilowatt-hour for a wholly electrified mine is less than it is for a mixed-power mine of equivalent production. It will be noted that Schedule IV provides a flat rate of 2.38 cents per kilowatt-hour, regardless of consumption.

One argument in favor of the purchase of electrical power is the saving of coal that will result. When generating electric power locally 2000 tons of coal per month may be consumed by the boilers of a mine. Under the purchased-power plan, this same amount of coal might be marketed, and its sale profit should properly be deducted from the power bills in arriving at relative power costs unless power plant fuel is figured at full market price.

An article* by the electrical engineer of one of Illinois' large operating companies gives excellent data regarding load demands and load factors. Although these data and their accompnying meter diagrams were derived from operations in mines whose electric power is generated locally, they are equally applicable to mines for which power is purchased.

XII. The Principal Factors That Affect Power Costs in Mining

42. *Unit Power Consumptions and Unit Power Costs.*—In undertaking this investigation the authors hoped that, in addition to ascertaining and placing on record the actual conditions regarding power

*Lee, Carl, "Relation Connected Loads Should Bear to Generator Capacity," Coal Age, June 22, 1922, p. 1037.

TABLE 12

TOTAL ENERGY CONSUMPTION PER TON OF COAL PRODUCED AT THE SELECTED MINES WHERE POWER IS USED FOR ALL MAJOR OPERATIONS

Mine Class and Number	Daily Tonnage	Hoisting Depth Feet	Thickness of Seam	Percentage of Actual Production to Capacity	Days Operated Per Year	Total Steam H. P.-Hr. per ton
E-9	1750	259	5 ft. 10 in.	87.5	160	1.33
D-35	3500	234	8 ft. 0 in.	77.0	149	1.69
D-19	2470	266	5 ft. 9 in.	103.0	212	2.03
C-20	2500	349	7 ft. 6 in.	87.4	125	2.20
C-25	2700	284	6 ft. 6 in.	100.0	154	2.24
C-15	2200	256	6 ft. 0 in.	88.0	170	2.37
D-11	2000	696	7 ft. 6 in.	47.0	151	2.44
C-8	1600	143	7 ft. 6 in.	80.0	216	2.46
F-50	3200	699	8 ft. 4 in.	87.0	175	2.52
F-31	3000	687	7 ft. 0 in.	63.8	136	2.53
C-47	4375	363	7 ft. 0 in.	58.5	218	2.57
C-49	4910	396	7 ft. 6 in.	87.5	199	2.73
D-34	3200	159	7 ft. 6 in.	92.0	225	2.79
D-41	4000	375	7 ft. 6 in.	84.0	149	2.80
C-48	4730	370	7 ft. 4 in.	84.5	194	2.88
C-29	3000	349	7 ft. 6 in.	79.0	122	2.92
D-42	4000	409	6 ft. 0 in.	89.0	200	2.98
C-44	4160	387	7 ft. 0 in.	83.5	196	3.06
C-14	2200	154	7 ft. 0 in.	88.0	171	3.12
D-16	2200	374	7 ft. 0 in.	73.5	156	3.21
D-18	2445	461	9 ft. 0 in.	74.0	192	3.29
C-40	4000	413	6 ft. 10 in.	100.0	235	3.41
C-22	2635	463	7 ft. 6 in.	59.0	222	3.41
D-58	6000	563	8 ft. 6 in.	80.5	211	3.48
C-24	2700	369	9 ft. 0 in.	90.0	100	3.51
C-45	4200	424	7 ft. 9 in.	....	235	3.57
C-30	3000	255	6 ft. 6 in.	67.0	200	3.61
D-46	4200	509	10 ft. 0 in.	93.5	....	3.73
D-33	3200	499	10 ft. 0 in.	80.0	200	3.81
D-28	2750	349	6 ft. 0 in.	74.0	275	3.94
C-39	4000	333	6 ft. 6 in.	90.0	235	3.98
F-26	2700	689	9 ft. 0 in.	90.0	....	4.00
G-38	3770	409	7 ft. 0 in.	94.0	217	4.25
F-32	3000	574	10 ft. 0 in.	86.0	....	4.27
D-13	2100	543	7 ft. 6 in.	96.0	175	4.31
D-57	3300	469	5 ft. 6 in.	82.5	250	4.35
G-37	3710	421	6 ft. 6 in.	92.5	207	4.40
G-43	4000	650	10 ft. 0 in.	89.0	180	4.59
C-5	1200	469	7 ft. 0 in.	86.0	172	5.46
G-36	3500	309	8 ft. 2 in.	70.0	160	5.97
C-1	650	181	4 ft. 9 in.	76.5	200	16.77
Average	3140	401	7 ft. 4.4 in.	82.7	187.5	3.63

generation and consumption at Illinois mines, they might make some practicable constructive application of their data to the problem of reducing the cost of mining coal. The tabulations herein have been carefully analyzed to determine how the unit power costs are affected by the various factors which might be expected to influence power costs and to locate opportunities for worth-while improvement in conditions. Some of these factors—such as depth, thickness of seam, and amount of water—are natural unchangeable conditions of the coal deposit, but others—such as tonnage production and power-plant equipment—are, in a large measure, subject to the operator's will.

In Table 12 the 41 mines which use power for all the major activities are arranged in order of increasing power consumptions per ton of coal produced. The tonnage, depth, seam thickness, number of operating days per year, and ratio of actual production to rated capacity at each mine are included to show how these conditions affect the power consumption and to ascertain, if possible, the reasons why certain mines are exceptionally high and others exceptionally low in power consumption per ton of coal mined. In Table 13 these same mines and also the mines of classes A, B, and E (which are not completely power-operated) are arranged in order of increasing power-plant costs per unit of power generated, with brief notes describing the power-generating equipment at each mine.

This separate study of power-production and power-consumption figures is necessary in order to allocate correctly losses to the power plant or to the mine. It will be observed that the order of arrangement of the mines in the two tables is entirely different, thus indicating that some of the mines which are efficient in the production of power are wasteful in its utilization, while for other mines the reverse is true.

A striking example of this is found in the condition at six mines, 11, 12, 20, 29, 31, and 35, all operated by one company and all high-cost mines as regards power. These six mines are grouped together at the bottom of Table 13, thus showing their high cost of power production. In Table 12, however, most of these mines are near the head of the list, showing lower power consumptions per ton of coal produced. These mines are efficient in the use of power and the high power costs per ton of coal mined are due entirely to lack of economy in the power plant. Mine 1, on the other hand, occupies a unique position in that, of all the mines studied, it has the lowest unit cost of power generation but the highest power consumption per ton of coal mined.

The average power consumption for all the mines is 3.63 steam horsepower-hours per ton of coal mined and the average cost of power generation is 2.874 cents per steam horsepower-hour. This makes the average power cost per ton of coal mined, at the completely power-operated mines, 10.43 cents per ton. Omitting the exceptionally high-cost and the exceptionally low-cost mines, the average figures are: for consumption per ton of coal mined, 3.31 hp.-hr., and for cost of power per steam horsepower-hour, 2.169 cents, or 7.18 cents per ton.

By selecting, in Tables 12 and 13, those mines which show close grouping of power-consumption and power-cost figures, averages were secured which are tentatively presented as representing normal power conditions. These figures are, for power consumption, the average in Table 12 of the 35 mines beginning with C-20 and extending down in the table to include G-43, this average being 3.31 steam horsepower-hours per ton. Similarly, figures for power cost are the average of the 35 mines in Table 13, commencing with 38 and ending with 41, this average being 1.898 cents per steam horsepower-hour. The product of these averages would make the power cost per ton of coal produced 6.283 cents. This latter figure, however, does not represent actual average costs at any group of mines, because the mines selected as normal are not the same in the two tables. Some that were considered normal with respect to power consumption were not given normal rating as regards power production cost, and vice versa.

The distribution of this total cost to the six major divisions is as follows: hoisting, 0.58 steam horsepower-hours, 1.10 cents per ton; ventilation, 0.76 steam horsepower-hours, 1.44 cents; pumping, 0.10 steam horsepower-hours, 0.19 cents; mining, 0.81 steam horsepower-hours, 1.54 cents; haulage, 0.72 steam horsepower-hours, 1.36 cents; and miscellaneous, 0.34 steam horsepower-hours, 0.65 cents; total, 3.31 steam horsepower-hours, 6.28 cents per ton.

Another group average which may be of interest is secured by selecting, arbitrarily, the first 25 per cent (omitting the exceptionally low in each table) as representing the best practice and efficiency in power production and power utilization. These figures are 2.41 steam horsepower-hours per ton for consumption and 1.373 cents per steam horsepower-hour for power cost—this item covering current boiler-room costs of fuel, labor, and maintenance, and in the case of purchased-power mines, actual power bills. The average power cost per ton of coal mined for the lowest 25 per cent of the mines studied (tabulation not shown) is 4.598 cents, as compared with 3.31 cents which would be attained by the 25 per cent of lowest power-consuming mines if they also secured their power at as low a unit cost as the 25 per cent lowest-cost power-producing mines. This, however, is not the case at most of these mines. In fact, mine 48 is the only one which is included in both groups. The average cost of power at the purchased-power mines is 1.794 cents per steam horsepower-hour, and at the 25 per cent of the lowest-cost generated-power mines, it is 1.657 cents.

43. *High-Cost Mines.*—Nine mines show total power costs of more than 10 cents per ton of coal produced. The excessive power cost at two of these may be attributed to the large amount of water handled.

These two are mine 35, at which the pumping cost is 4.685 cents per ton of coal hoisted, and mine 1, at which the pumping cost is 6.992 cents per ton of coal handled, the pumps in this latter case taking more than half the total power.

At three of the other exceptionally high-cost mines, the highest item is ventilation, but there is not such a marked concentration of the cost in this one operation, all items being comparatively high because of the high cost of power generation. These mines are 13, 20, and 29. The ventilating pressures reported at these mines (2¾-in., 1⅞-in., and 3¼-in.) are somewhat higher than the average.

At mines 11 and 31, the highest cost items are for hoisting, which fact may be attributable to the depths—696 feet and 687 feet—which are greater than at most of the mines considered, although there are others of equal depth with considerably lower power costs for hoisting. At these two mines, also, the principal cause of high power cost is in the power plant.

Aside from these exceptional cases, the major factors that may be expected to influence the total power cost at the average mine are: the size of the mine, as indicated by production or capacity; the depth and thickness of the coal seam; the age or extent of underground workings; the ratio of working days to idle days; the ratio of actual production to capacity; the type of power-generating equipment; and the efficiency in management and operation.

Some of these factors have been discussed already and need be summarized only. It is difficult in a study of this kind to evaluate any one of these variable factors because it cannot be isolated and its effects noted while all other conditions are kept constant, as is done in laboratory experimentation. For this reason, only general tendencies in the group of mines as a whole can be ascertained and that, in some cases, with no great degree of precision.

44. *Effect of Size of Mine.*—The relation of the size of the mine, as stated in terms of daily production, to the various items of power cost is discussed in detail in Chapter X, "Power Requirements at Mixed-Power Mines." At the larger mines some of the items of power consumption are relatively large while other items, e.g., ventilation, pumping, and mining are smaller than at the smaller mines. Therefore, the relation of scale of operations to total power consumption is problematical. In Table 12, however, while the mines of large production appear more or less promiscuously throughout the list, they are grouped,

for the most part, in the middle part of the table, thus showing average unit power consumption. This is most logically interpreted as indicating that the larger mines make more extensive use of power than do the smaller mines at the head of the list, but probably use it more efficiently than do the smaller mines at the bottom of the list.

45. *Effect of Depth and Thickness of Coal Seam.*—Because so many other factors enter into the power consumption at mines, the effect of depth, which affects the hoisting item only, is not readily apparent in the table of total mining-power requirements. The same is true in regard to thickness of seam, which affects principally the cost of cutting, although, in this case, the other activities also are affected indirectly. There is not, however, a sufficient range of seam thicknesses at the mines studied to determine the relation of seam thickness to mining-power costs except as it affects the one item of cutting, which apparently is inversely proportional to the thickness.

46. *Ratio of Idle Days to Working Days.*—Study of the power-consumption figures for individual mines shows that the power cost per ton of coal produced increases with the ratio of idle days to working days. In other words, the power cost (as well as other items in the cost of producing coal) is much greater when the mine is operated irregularly than when steady continuous production is maintained. A higher power cost is entailed by a production that is small as compared with the capacity of the mine equipment. When a mine is designed for a certain rated capacity and the mechanical equipment is selected to mine, transport, and prepare that tonnage, the mine will obviously operate most efficiently at or above the rate intended. When the mine is producing only a small part of its rated capacity, during the development period or at any other time, unit operating costs, including power, will be high. The effect of these factors is shown by the general trend in Tables 12 and 13, although there are many exceptions due to many other conditions that have a bearing on power consumptions.

An instance of the effect on power cost of steady and of irregular operation, respectively, is furnished by the power-consumption records of the Kathleen mine at Dowell, Illinois, which were made public* in an article by Eugene McAuliffe, formerly president of the operating company. This author concluded that "Whenever a reasonably steady

*Records at Kathleen Mine show that when running time is halved, power costs per ton mined are doubled; Eugene McAuliffe, Coal Age, May 18, 1922.

TABLE 13

POWER GENERATION COSTS AND POWER-PLANT EQUIPMENTS

Key to Symbols: HRT, Horizontal return tubular boilers; WT, water tube boilers; H, hand-fired; M, mechanical stokers; P, electric power purchased; N, electric power received from a neighboring mine; E, generators engine driven; T, generators turbine driven; MG, motor-generator sets; R, rotary converters

Mine Class	No.	Daily Tonnage	Power Cost Cents per Steam H. P.-Hr.	Boiler Plant and Generating Equipment
C	1	650	0.798	HRT H 125 kw. 250 v d.c. E
C	40	4000	0.859	HRT H 100 kw. 250 v d.c. E N MG
C	24	2700	1.076	HRT H 200 kw. 275 v d.c. E
F	32	3000	1.128	HRT H 300 kw. 275 v d.c. E P MG
E	38	3770	1.215	HRT H P MG
D	28	2750	1.216	WT M P MG
B	21	2600	1.260	WT H 300 kw. 275 v d.c. E
B	22	2635	1.289	P MG
B	36	3500	1.366	P MG
G	37	3710	1.489	P MG
F	26	2700	1.585	HRT H 450 kw. v d.c. E P MG
D	18	2470	1.613	HRT H 450 kw. 250 v d.c. E
C	49	4910	1.627	HRT WT H 200 kw. 250 v d.c. E P MG
C	45	4200	1.677	HRT H 300 kw. 250 v d.c. E
C	44	4160	1.714	HRT H 400 kw. 275 v d.c. E 500 kv-a 2300 v a.c. T MG
B	7	1500	1.730	HRT H N
C	48	4730	1.745	HRT H 400 kw. 250 v d.c. E 500 kv-a 2300 v a.c. T MG
D	46	4200	1.764	WT M N MG
C	8	1600	1.772	HRT H 260 kw. 250 v d.c. E
D	58	6000	1.776	WT M 1100 kw. 250 v d.c. E
D	57	3300	1.829	HRT H 650 kw. 275 v d.c. E
D	33	3200	1.859	HRT H 725 kw. 275 v d.c. E
C	15	2200	1.941	HRT WT H 300 kw. 250 v d.c. E
D	16	2200	1.943	HRT H 200 kw. 250 v d.c. E
D	34	3200	2.070	HRT M 400 kw. 250 v d.c. E
C	39	4000	2.130	WT M 150 kw. 275 v d.c. E 800 kv-a 2200 v d.c. T MG
G	43	4000	2.144	HRT H 5000 kv-a. 2300 v a.c. T MG
C	30	3000	2.145	HRT H 900 kw. 275 v d.c. E
D	42	4000	2.229	HRT M 400 kw. 250 v d.c. E
C	47	4375	2.322	WT M 1300 kv-a. 2300 v a.c. T 25 kw. 250 v d.c. E R
C	5	1200	2.407	HRT WT H 200 kw. 250 v d.c. E
C	14	2200	2.523	HRT H 400 kw. 300 v d.c. E
E	9	1750	2.639	HRT H P MG
D	13	2100	2.919	HRT H 425 kv-a. 3300 v a.c. E MG
D	41	4000	2.921	HRT H 550 kw. 250 v d.c. E
F	50	5200	3.568	HRT H 1300 kv-a. 2300 v a.c. T MG
C	25	2700	3.614	P R
A	6	1250	4.459	HRT H P MG
C	29	3000	4.719	WT M 550 kw. 250 v d.c. E
D	19	2470	4.922	HRT H 350 kw. 250 v d.c. E
A	4	1025	5.605	HRT H 75 kw. 230 v d.c. E
D	11	2000	6.947	HRT H 450 kw. 250 v d.c. E
F	31	3000	1.403	HRT H 580 kw. 250 v d.c. E
D	35	3500	7.963	WT M 530 kw. 250 v d.c. E T
C	20	2500	8.218	HRT H 300 kw. 250 v d.c. E
B	12	2000	11.969	WT HRT M 325 kw. 250 v d.c. E

run can be obtained in the coal-mining field, the cost of power will be reduced by that fact in the same proportion as other items of expense. With 9.69 working days in July, 1921, the cost of power at this mine amounted to 13.36 cents per ton of coal produced, whereas in March,

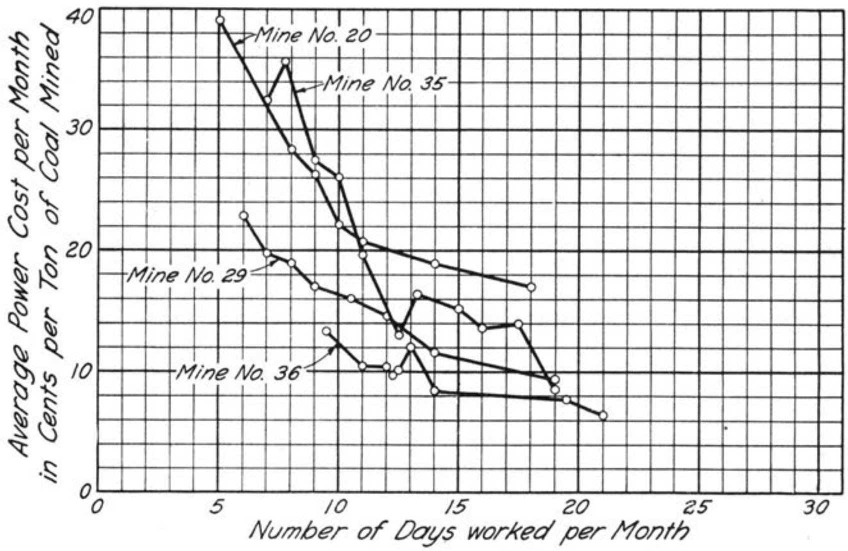

FIG. 3. RELATION OF POWER COST TO STEADINESS OF OPERATION

1922, when the mine worked 21 days, the power cost was only 6.43 cents per ton."

In Fig. 3 monthly average power costs per ton of coal mined at four individual mines are plotted with respect to the number of days worked. The general trend of these graphs shows the bearing, upon the power cost of producing coal, of the much discussed problem of irregular mine operation.

47. *Power-Generating Equipment.*—In Table 13 are given the power costs per steam horsepower-hour, and a brief description of the power-generating equipment is included to show the relation, if any, of type of power plant to power-generating costs. It is impossible, however, to base any specific conclusion on the data which were secured. It will be observed that the distribution of the few plants which one would designate up-to-date is rather promiscuous and shows no apparent relation between type of equipment and cost of generating power. We must concede, however, that such a relation exists, at least potentially, in favor of the better equipped power plant. The fact that a comparison of various mines gives little information as to the value of this factor or, indeed, of many other factors that logically have a direct bearing on mine-

power cost, merely proves that each mine presents unique conditions calling for individual study in evaluating such factors precisely.

The individual factor is, therefore, probably the greatest influence in determining power cost and such part of this individuality as is subject to change might be designated as the efficiency of management and operation. A discussion of typical inefficient operating conditions observed during the course of the investigation and remedial suggestions may, therefore, prove more helpful than general interpretation of the data collected. That the methods of power generation, power transmission, and power utilization in use at mining plants are, in many cases, wasteful and inefficient, is common knowledge. The following comments and suggestions, therefore, are not new. Some of them may be considered so self-evident as to be unnecessary. The fact that such conditions continue to exist at many mines indicates, however, that their importance is not always fully appreciated.

48. *Efficient Power Production.*—A power-efficiency study, like a power-accounting method, logically divides itself into two main branches, namely, power generation and power utilization. The first of these two subjects—efficient power generation—received little consideration in the Illinois field until recent years when the greatly increased cost of mining coal has led many operators to attempt a more economical use of fuel and to pay more attention to power-generation costs. Several efficient mine power-plant installations have been made in the state in recent years, and many operators have sweeping power-plant changes under consideration.

The principal improvements contemplated to bring about more economical power production than is secured in the typical mine power plant (with hand-fired, horizontal, return-tubular boilers and engine-driven d.c. generators) are the introduction of water-tube boilers, mechanical stokers, and condensing steam-turbine alternating-current generator sets. Low-pressure or mixed-pressure turbines, utilizing exhaust steam from the hoisting engines, have been installed at several mines in the state and have considerably reduced the cost of power generation. The increasing value of fuel at the mine and the higher cost of labor have made these refinements in power-plant equipment profitable wherever the scale of operations and the anticipated life of the properties are sufficient to justify the increased capital outlay.

The opportunity is correspondingly greater in the case of neighboring mines under common ownership so located that one central power plant can supply all these mines by short high-tension transmission lines. Such centrally located power plants are operated by several mining companies in the state. Outside of this field, a noteworthy example is the modern anthracite dust-burning plant of the Susquehanna Colleries Company at Lykens, Pennsylvania. This plant supplies both electricity and steam to the three operations of this company in the vicinity of Lykens and, moreover, uses for fuel practically unmarketable culm screened out of old banks, the better part of which is briquetted by the American Briquet Company. This case exemplifies the economy that may be effected by utilizing waste fuels or such part of the production as may be unmarketable. This practice is common in the Illinois field. It should be pointed out that there are disadvantages such as lessened efficiencies, increased fuel and ash handling, and decreased capacities of equipment which compensate in a measure for the saving in fuel cost, so that each installation of this kind requires careful study. It is commonly understood that such low-grade, high-ash fuels are better adapted to combustion in the pulverized form than on grates, and that the pulverized coal plant is probably most efficient in the utilization of such fuels. The introduction of dust-burning power plants at Illinois mines should perhaps be considered only as an innovation that might be worthy of consideration in special cases.

Use of the power plant for profitable disposal of unmarketable fuel is exemplified at another eastern operation where, in order to produce a cleaner coal for coking purposes, it is planned to erect a washery and to install a large power plant that will consume the entire production of secondary coal from the washery. The power not required in the operation of the mine will be sold to near-by industrial plants. This company thus plans to go into the power business to market its unsalable secondary coal product.

49. *Efficient Power Transmission.*—Perhaps the most significant single source of power loss in a mining operation is the underground power-transmission system. This part of the mining plant is often found in poor condition. It is difficult to maintain the system so that it will function efficiently when the underground workings are extensive and the electrical power is transmitted at low voltage direct from the generators on top to the machines at the face. Under these conditions it becomes increasingly difficult to operate the underground electrical machinery as the workings are extended and transmission lines are lengthened. It is not uncommon for mining machines and gathering

motors to fail to operate in remote sections of mines because of too low voltage, due to long and inefficient transmission lines. A mine power plant generating direct current at 250 or 275 volts may deliver the current at the working face with a potential as low as 140 volts. If designed for 250 volts, the machines, to develop the necessary power on 140 volts, require an abnormally large current which increases the heat losses in the transmission line and machine. The power requirements under these conditions may become greater than the power plant can supply and the vital operations at the working face are so slowed down as to reduce materially the rate of coal production. Even if sufficient power be available the mining and haulage motors, which are not designed for such low voltages, will not develop their full-load capacities. The indirect effects of these conditions, in lessened coal production and increased equipment necessary to supply sufficient power, make the question of underground transmission efficiency much more important than is indicated by the increased power cost, which is itself a relatively small part of the total cost of coal production.

The remediable causes of excessive transmission-line losses are: inadequate sizes of conductors, grounded cables, poor trolley-wire connections, and inefficient bonding of rails. The effects of these losses are commonly known but the magnitude of the power losses entailed is probably not fully appreciated. The value of adequate transmission lines in continuous operating condition is shown by the records of several individual mines where the power plants, which had been operated to full capacities to supply the power required, were able, with very little additional equipment, but with efficiently reconstructed transmission systems, to supply all the power required in the production of doubled daily outputs.

Even with the best transmission conditions that can be maintained underground, the power losses and the investment in copper increase formidably as a mine becomes older and the transmission lines for carrying low-voltage current are lengthened. In order to remedy these conditions the underground converter station has been introduced into the mine power system. A great decrease, both in transmission-line losses and the amount of copper required, is effected by transmitting power as alternating current at high voltage to substations near the centers of power consumption and there converting it into low-voltage, direct current, to be transmitted over short distances to the mining machines and locomotives. The approved practice is to carry the high-tension alternating current over surface transmission lines to points directly above the substations and thence by cables through bore-holes from the surface to these stations. At these points, motor-generator sets or transformer and rotary-converter equipment alter the high-potential alternating current to 250-volt direct current. The motor-generator set has been commonly used because of the difficulties formerly experienced in the operation of 60-cycle synchronous converters. The recent perfection of the latter type of machine by the use of inter-poles has made this type of converting equipment adaptable to mining use and some installations have been made. These have the advantages over the motor-generator set of lower cost, higher efficiency, and the possibility of adjusting the power factor, which cannot be accomplished with the induction motor-generator set. The disadvantages in the use of the rotary converter are that transformers are required and more care is necessary in starting the synchronous rotary, because it must be started, brought up to speed, and synchronized with the power source before it may be connected with the power line.

Some have advocated the elimination of the converter equipment and direct-current commutation troubles by the use of alternating-current equipment for all mining work. There are, however, the compensating disadvantages of the lack of flexibility in operation of alternating-current motors, low starting torque, the greater amount of copper required for power transmission at a given low voltage, and the low power-factor when induction motors are used. Power factors as low as 30 per cent have been reported in the case of alternating-current mining-machine circuits and a power factor of 60 per cent for the entire mine is considered average practice.

It is hardly necessary to mention condensation losses in long steam lines and bare steam pipes. Electrification of remote power-consuming machines is now the common practice and is an established condition at most Illinois mines although changes still are to be made. While the importance of adequate steam-pipe covering is generally recognized, it is not uncommon to find at mining plants live steam being transmitted to considerable distances through bare pipes.

50. *Time Study of Mechanical Operations.*—There are, no doubt, cases in which a saving in power cost, a more important saving in labor cost, and an increase in production may be effected by a careful analysis of the time schedule in hoisting, haulage, and mining operations. The principal object to be gained, so far as power is concerned, is an improvement in the load factor by so timing operations as to result in a steadier

demand for power. While changes in hoisting and main-haulage time schedules may be difficult at large mines whose capacities are crowded, the mining-machine and gathering-motor operations are, in many cases, open to improvement. Slower and steadier operation of these branches of the work would, in some cases, result advantageously both as regards uniformity of power consumption and tonnage produced per machine.

Illinois coal mines, with few exceptions, are comparatively dry and the cost of pumping is, in the majority of cases, almost negligible. In some cases, gathering pumps are forcing water for long distances through very small pipe-lines and the friction head is large. Where the quantity of water handled is small (as it is in most of the mines), the installation of larger pipes would necessitate an increased capital expenditure which the small power saving would not justify. For this reason, therefore, the pumping system must remain mechanically inefficient in many mines.

Haulage-road improvements at many mines, while made primarily to increase the output and to improve the general efficiency and dependability of operation of locomotives and men, are resulting in more economical use of power. A rapidly growing use of heavier rails and heavier locomotives, a readiness to make expenditures for improving grades and curves, and the general introduction of standard railway practice on main-haulage roads make for steadier and more dependable operation, larger production, and lower power costs. Under such conditions, which are becoming the rule rather than the exception in the large mines of Illinois, locomotive performance compares favorably with that of surface haulage units. One factor which too frequently is overlooked is the drainage of main-haulage ways. Otherwise well-maintained main-haulage roads frequently have an underflow of water, which, while apparently negligible in amount, corrodes the rails and bonds and seriously interferes with the transmission of power.

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